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Technical Report

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COATING STUDIES AT KWAJALEIN, KANEOHE, AND PORT HUENEME

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U. S. NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

COATING STUDIES AT KWAJALEIN, KANEOHE, AND PORT HUENEME

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Type C

by

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OBJECT OF TASK

To provide information concerning the corrosion of metals and alloys and the effectiveness of protective coatings exposed to marine atmospheres.

ABSTRACT

Twenty-nine protective coating systems were applied to sand-blasted steel test panels and placed on exposure in the marine atmospheres of Kwajalein, Marshall Islands; Kaneohe, Hawaii; and Port Hueneme, California.

A mica-filled asphalt emulsion applied over a wash primer and a zinc chromate primer gave excellent protection to both scribed and unscribed panels for 5 years. Four additional coating systems gave, for the same period of time, protection which was superior to that given by the selected standard test coating, Saran.

CONTENTS

BACKGROUND

This task was undertaken by the Naval Civil Engineering Laboratory in 1951 to provide information concerning the corrosion resistance of metals exposed to the marine environment at Port Hueneme. In 1954, the Bureau of Yards and Docks suggested that this Laboratory and the 14th Naval District integrate their separate programs for protective coatings and metals. In 1955, the scope of the work was modified to emphasize the evaluation of protective coatings in the marine atmospheric environments at Port Hueneme, California; Kaneohe, Hawaii; and Kwajalein, Marshall Islands. Because of the difference in temperature, humidity, solar radiation, and salt spray, simultaneous exposure studies were initiated on identical coatings at the three separate exposure sites. A standardized rating procedure was established, and the Laboratory sent the first shipment of coated test panels to the 14th Naval District in December 1955.

TEST PROCEDURE

Laboratory Analyses

All paint coatings tested were analyzed to determine physical properties and composition. Analyses were based on methods specified in Federal Specification TT-P-141[1]; ASTM Standards, Part 8[2]; and Physical and Chemical Examination.[3] The physical propertied determined included weight per gallon, specific gravity, and viscosity. Composition analyses were made to determine the amounts of non-volatile solids, total pigment, non-volatile vehicl and, where applicable, the amount of ash. Infrared spectrograms were prepared from the amine catalysts of the epoxy coatings and were used to show the presence of amides in some of the catalysts. Results of the Laboratory analyses appear in Appendix A.

Panel Preparation

The surface preparation of the test panels was by sandblasting to a uniform, gray mat finish.* Six panels were prepared for each coating system

* In accordance with section 1, 5.02, paragraph 2, of BUDOCKS Technical Publication, Navdocks TP-PW-30.

The coating systems were applied in accordance with the manufacturer's or Navy instructions, and during periods of fair weather in a covered shelter protected from wind and dust. After being coated, the panels were dried or cured (as required for the particular coating). In order to evaluate loss of adhesion and blistering of a coating associated with corrosion at a break in the coating, a diagonal cut was made through the coating to the bare steel, on one side of three of the six panels. This cut, a 1/32-inch wide "X," was made with a scribing tool.

Two of the six panels, one scribed and one unscribed, were placed on atmospheric exposure racks at each of the three test sites, Port Hueneme, Kaneohe and Kwajalein.

The size of test panels was originally 12 by 14 by 1/8 inches, and was later changed to 4 by 9 by 1/8 inches because of limited rack space at Kwajalein. But now, all test panels being coated for exposure tests are 6 by 12 by 1/8 inches, giving approximately one square foot over-all coating area. The panel edges are rounded prior to coating to minimize edge failures. Appendix B presents a list of all the coatings with a system description and the thickness applied.

Exposure Racks

Port Hueneme. The steel exposure racks at Port Hueneme face south with the panels at a 30-degree angle to the horizontal and are about 200 feet from the surf. The prevailing wind is from the west, and at high tide, a fine salt spray is carried to the panels. Silicon bronze bolts with porcelain insulators hold the test panels in place on the racks.

Kaneohe. The wooden exposure racks at Kaneohe face east northeast into the prevailing wind and are about 450 feet from the surf. Bolted procelain insulators hold the panels in place at an angle of 45 degrees to the horizontal. The wind often carries small amounts of sand and grit which are slightly abrasive to the face of the panels.

Kwajalein. The wooden exposure racks at Kwajalein are about 75 feet from the surf at high tide and hold the panels facing east northeast at an angle of about 45 degrees to the horizontal. Galvanized nails secure the porcelain insulators. The prevailing east northeast wind continually carries large amounts of salt spray onto the panels.

Rating of Systems

The rating system used by the personnel of NCEL and the 14th Naval District is in accordance with ASTM standards.[2] A numerical rating system is used for recording the degree of protection given by a coating; a rating of 10 indicates complete

protection, and a rating of 0 indicates no protection. If, for instance, the loss of protection to the metal substrate occurs over 20 percent of the panel surface, the coating would be given a rating of 8. For the purpose of this report, a rating of 7 indicates coating failure. Ratings assigned to the coatings are tabulated in Appendix C.

Chalking is evident in removable powder evolving from the paint film at, or just beneath, the surface. It was determined by making a 4-inch stroke across the surface of the paint with a clean, dry cloth. A comparison of the powder spot on the cloth with photographic reference standards (ASTM Designation D 659-44)[2] rates the degree of chalking from 10 (no powder on the cloth) to 2 (the spot on the cloth completely covered with powder). Chalking on the paint film at the time of rating was affected by any recent rainfall. The recorded rating in Appendix C represents an average value for chalking.

The degree of blistering was also rated in accordance with photographic standards (ASTM Designation D 714-56).[2] The blister size is also designated 10 to 2; 10 indicates no blisters, 8 indicates the smallest blister easily seen with the unaided eye, and 6, 4, and 2 represent progressively larger sizes. Size 2 represents a blister diameter of about 1/8 inch or over. The frequency of occurrence of blisters is reported as dense (D), medium dense (MD), medium (M), and few (F), where "dense" represents complete surface coverage, and "few" only occasional blistering. Thus, a rating of 2/M would represent blisters of 1/8 inch or over occurring over possibly one-third of the surface.

For classifying the coating systems relative to the protection they gave to the test panels, Saran (System 23), was used as a high-quality standard.[4,5]

Treatment of Data

The data, obtained by periodic rating of the coated test panels at the three test sites, are reported here in three series based on the length of time the coating was on exposure. Series I includes all coatings which have been on exposure about 5-1/2 years; Series II, those exposed 2-1/2 to 4 years; and Series III, those exposed 1-1/2 to 2-1/2 years. The different lengths of time between exposures at Port Hueneme and those at the 14th Naval District test sites were the result of shipping delays, rack damage, weather conditions, and the availability of materials required to place the test panels on exposure as they were received.

Photographs accompanying the text illustrate the relative corrosiveness at the three test sites. The photograph for each set of test panels shows the condition of the coating, either at the time the panel was removed from test because of coating failure on the scribed panel, or if failure has not occurred, at the time of the most recent inspection. The length of exposure to the marine atmosphere at each test site appears beneath each photograph.

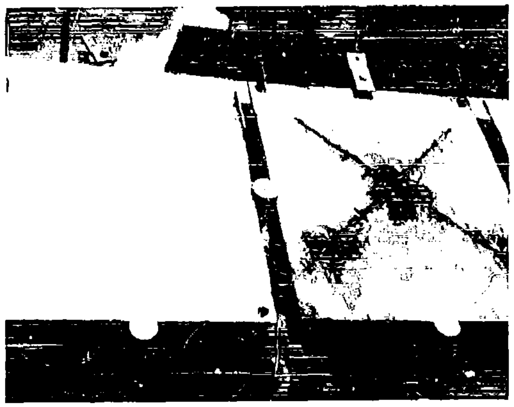
SERIES I. COATINGS EXPOSED UP TO 5-1/2 YEARS

System 1. Aluminum-pigmented Vinyl Resin. This system (spray-applied) consisted of one coat of wash primer (MIL-C-15328), two coats of vinyl red lead primer (MIL-C-15929), and two coats of aluminum-pigmented vinyl resin topcoat. The total average thickness was 6 mils.

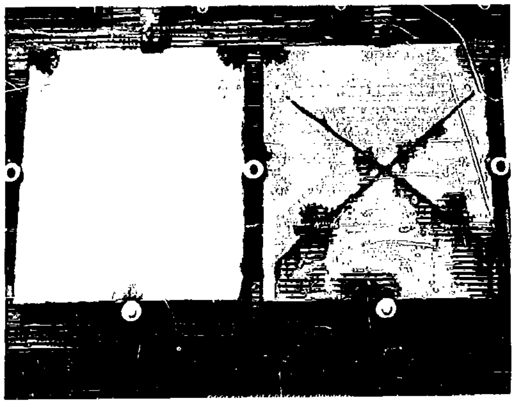
On the scribed panels this system failed at Kwajalein after 4-1/2 years as a result of blistering and rusting and was removed from test. The degree of blistering at the scribe was rated 2/M at Kaneohe after 5 years and 2/F at Port Hueneme after 5-1/2 years; protection was rated 8 and 10, respectively. Light rusting was occurring in the scribed mark at these two test sites.

The unscribed panels, after 5 years at the three test sites, have received very good protection, except at mechanical breaks or pinholes which exposed the steel substrate. Also slight rusting and blistering, aggravated to some extent by edge effects, has occurred at the corners and sides of the test panels that remain on exposure. The over-all rating for the unscribed panel at each test site was 9 at Kwajalein and Kaneohe and 10 at Port Hueneme.

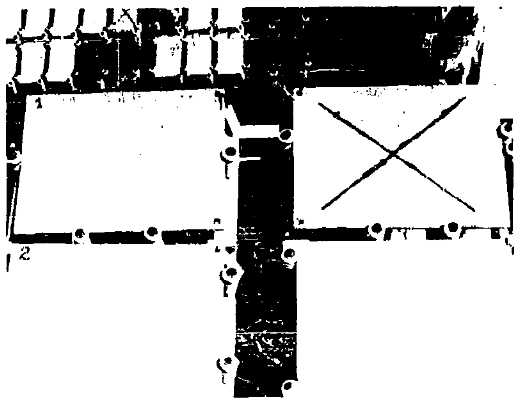
Chalking was light at each of the three test sites and was rated 8.



Kwajalein, 4-1/2 years



Kaneohe, 5 years



Port Hueneme, 5-1/2 years

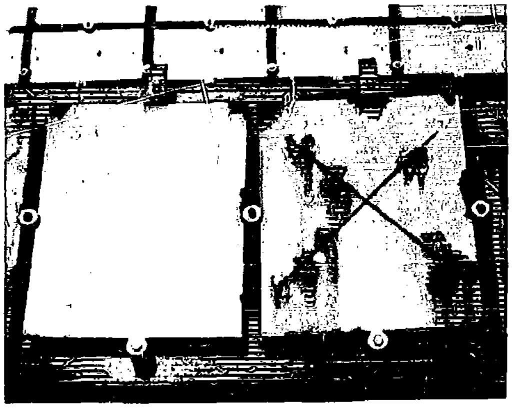
System 3. Epoxy Resin. This system (spray-applied) consisted of two primer coats of a catalyzed red lead epoxy and three finish coats of a catalyzed epoxy resin. The total average thickness was 8.5 mils.

The scribed panel failed at Kwajalein in 3 years because of blistering and rusting originating at the scribe, and was removed from test. Blistering of the scribed panel at Kaneohe after 5 years was rated 2/MD and protection was rated 8; at Port Hueneme after 5-1/2 years the coating was rated 10 on over-all protection.

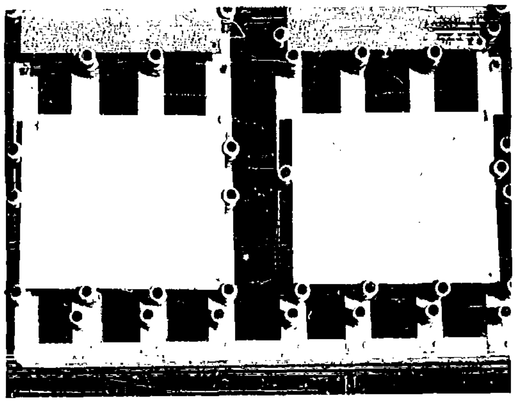
This system has given very good protection to the unscribed test panel at Kwajalein (rate 9) after 5-1/2 years exposure and excellent protection (rate 10) at Kaneohe and Port Hueneme after 5 and 5-1/2 years, respectively. The initial failure of this coating on the unscribed panels was progressing from the edges and corners and was most pronounced at Kwajalein.

Chalking was rated 6.

Kwajalein, 3 years



Kaneohe, 5 years



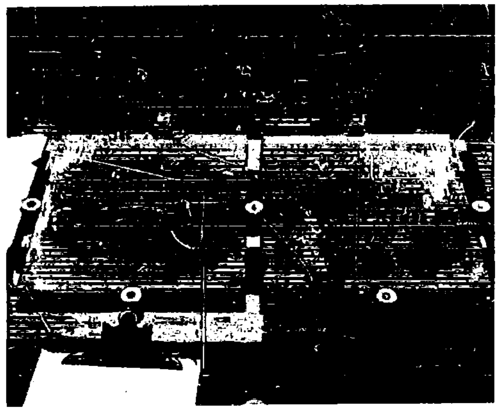
Port Hueneme, 5-1/2 years

System 4. Zinc-dust-pigmented Inorganic Silicate. This coating was spray-applied in two coats to a total average thickness of 3.5 mils. The chemical curing solution was brushed on approximately two hours after the application of each coat of the zinc-dust-pigmented inorganic silicate.

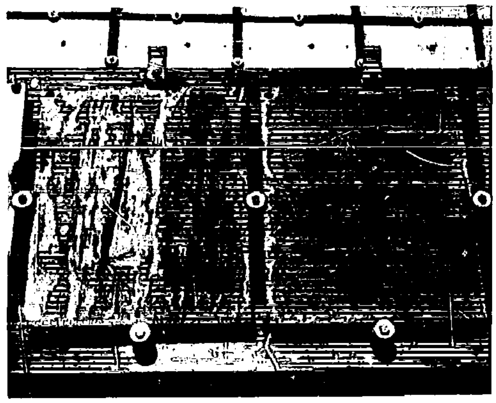
No rusting has occurred along the scribed mark on any of the test panels at the three sites.

The presence of zinc salts has caused discoloration over most of the surface of these test panels. A small amount of red iron rust was present over most of the surface at pinholes in the coating of the panels exposed at Kwajalein for 5-1/2 years. This type of failure was found only at the edges of the panels exposed at Kaneohe for 5 years and at Port Hueneme for 5-1/2 years. The over-all protection of the panels at Kwajalein was rated 8 and at Kaneohe and Port Hueneme 9.

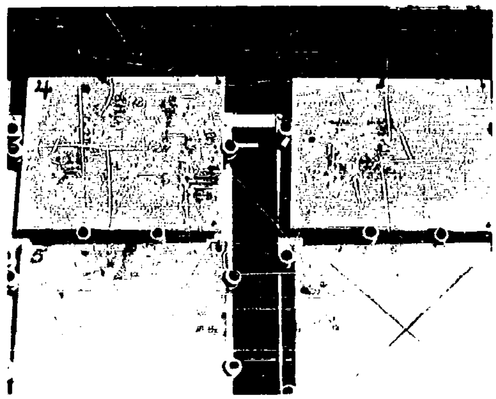
There was no chalking on this coating.



Kwajalein, 5-1/2 years



Kaneohe, 5 years



Port Hueneme, 5-1/2 years

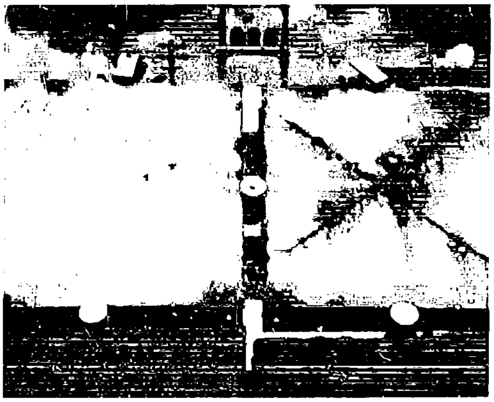
System 5. Vinyl Resin. This system (spray-applied) consisted of one coat of a vinyl resin primer and two of a vinyl resin topcoat. The total average thickness was 5.5 mils.

This vinyl system failed because of blistering and rusting along the scribed mark at Kwajalein after 4-1/2 years and was removed from test. The scribed panel at Kaneohe has only a few blisters (2/F) and light rusting after 5 years, and the scribed panel at Port Hueneme has no blisters after 5-1/2 years.

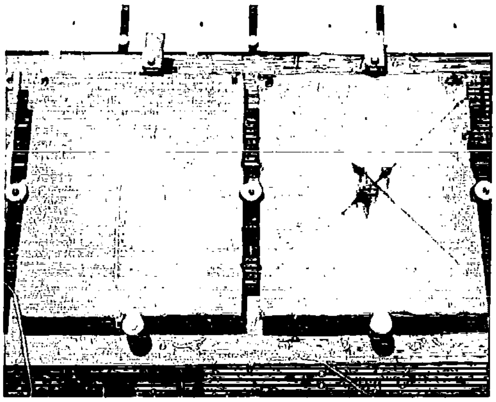
The unscribed panel at Kaneohe after 5 years and at Port Hueneme after 5-1/2 years was rated 10; the unscribed panel at Kwajalein was rated 9 after 4-1/2 years. The first signs of failure on the unscribed panel at Kaneohe and Port Hueneme were found at edges and corners. Coating breakdown has also occurred at pinhole breaks in the coating.

After 5-1/2 years at Kwajalein (not shown) the protection to the unscribed panel was rated 8.

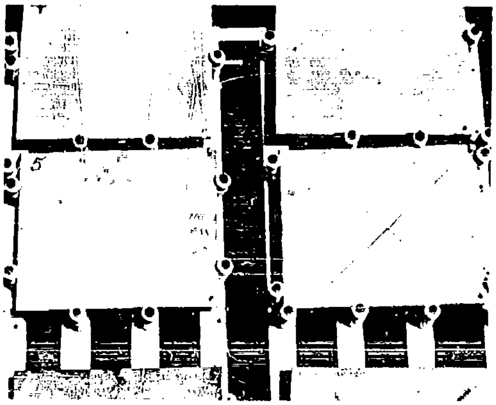
Chalking was very light and was rated 8.



Kwajalein, 4-1/2 years



Kaneohe, 5 years



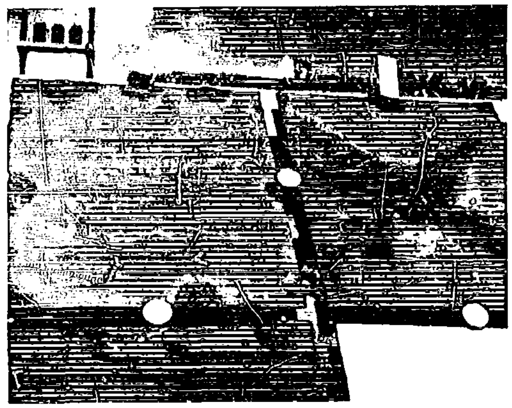
Port Hueneme, 5-1/2 years

System 6. Vinyl Resin Mastic. This system (spray-applied) consisted of one coat of vinyl resin primer and two vinyl mastic topcoats. The total average thickness was 13 mils.

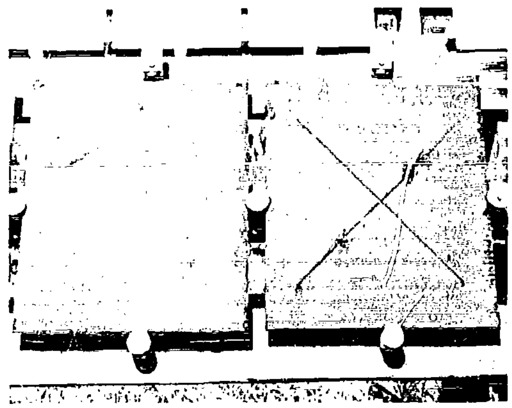
The vinyl mastic failed along the scribed mark, after 4-1/2 years at Kwajalein, because of blistering and was removed from test. Only a few blisters (rated 2/F) had appeared along the scribed mark at Kaneohe after 5 years, and no blistering was present after 5-1/2 years at Port Hueneme.

The unscribed panel was rated 9 after 5-1/2 years at Kwajalein. Failure started with the formation of blisters and rusting at corners and edges. The unscribed panel was rated 10 after 5 years at Kaneohe and 5-1/2 years at Port Hueneme. Only very slight evidence of weathering was found at the edges and corners of these panels.

There was slight chalking after 5 years, and the coating was rated 8.



Kwajalein, 4-1/2 years



Kaneohe, 5 years

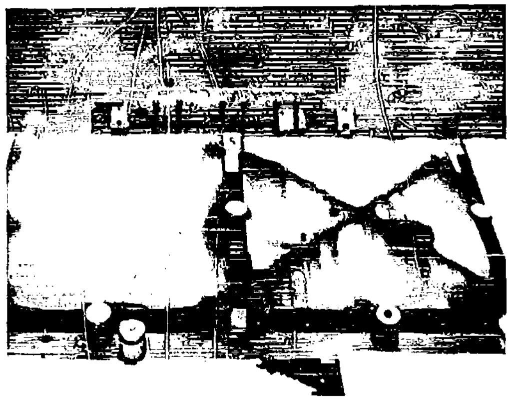
Port Hueneme, 5-1/2 years

System 7. Phenolic Resin Mastic. This system (spray-applied) consisted of one coat of a catalyzed mica-filled modified phenolic mastic primer and one coat of a catalyzed modified phenolic mastic finish. The total average thickness was 15 mils.

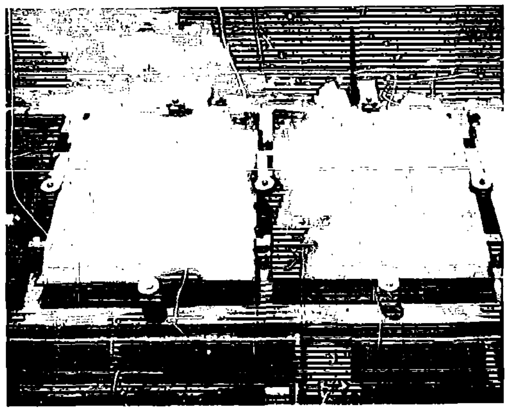
The blistering of this coating at the scribed mark was rated 2/MD after 5-1/2 years exposure at Kwajalein. Although heavy rusting along the scribed mark was causing discoloration of the paint film, the over-all protection given by this coating was rated 7. After 5 years at Kaneohe, rusting along the scribed mark was light, and blistering was rated 2/F. At Port Hueneme, no blistering had occurred along the scribe after 5-1/2 years.

The protection given to the unscribed panel was rated 8 at Kwajalein, 9 at Kaneohe, and 10 at Port Hueneme. Failure of the coating on the unscribed panels has proceeded from the corners and edges.

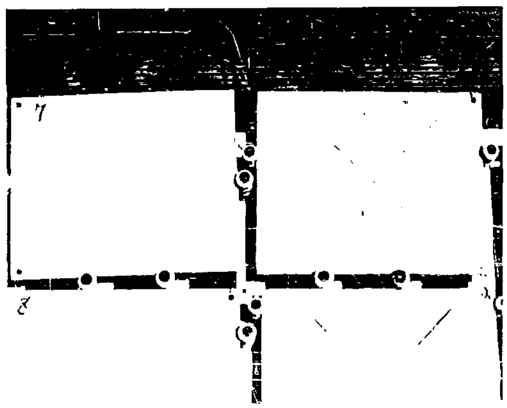
Chalking was moderate and was rated 6.



Kwajalein, 5-1/2 years



Kaneohe, 5 years



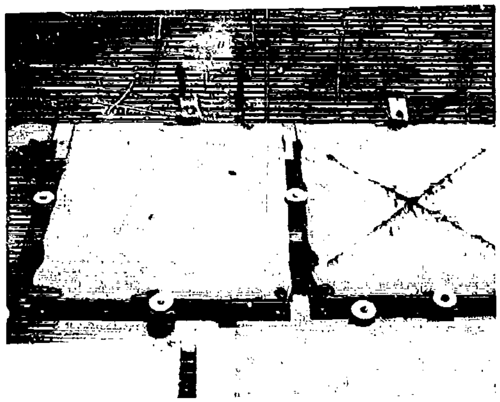
Port Hueneme, 5-1/2 years

System 8. Furan Resin Mastic. This system (spray-applied) consisted of one coat of an iron-oxide vinyl primer and six coats of a furan resin topcoat. The total average thickness was 6.0 mils.

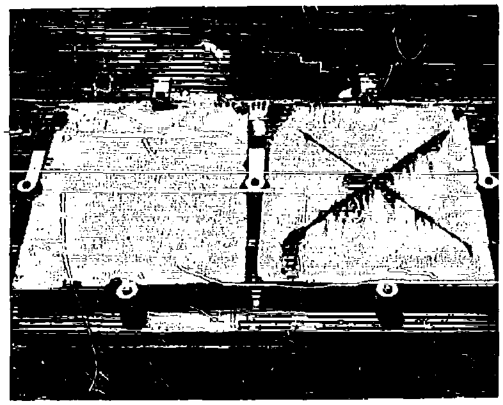
Blistering, rated 2/MD, and considerable rusting have occurred along the scribed mark, during 5-1/2 years at Kwajalein and 5 years at Kaneohe. However, the over-all protection was rated 7. No blistering has occurred along the scribed mark after 5-1/2 years at Port Hueneme.

Initial attack by blistering and rusting has occurred at the corners and edges of the unscribed panels at Kwajalein and Kaneohe, and the panels were rated 9. The panel at Port Hueneme was rated 10.

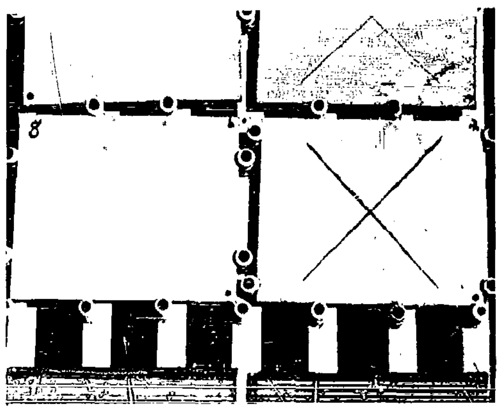
Chalking was moderate and was rated 6.



Kwajalein, 5-1/2 years



Kaneohe, 5 years



Port Hueneme, 5-1/2 years

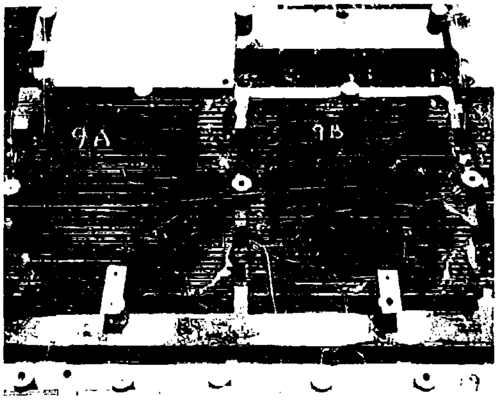
System 9. Neoprene Brushing Composition. This system consisted of one brushed coat of neoprene primer and four brushed coats of catalyzed neoprene topcoat. The total average thickness was 31 mils.

The blistering along the scribed mark was rated 2/D after 5-1/2 years at Kwajalein and was aggravated by slight undercutting. This failure had not progressed outward from the scribed mark to any extent, but because of rusting, blistering, and undercutting at the corners and edges, the over-all rating was 6, and the panel was removed from exposure. The scribed panel at Kaneohe after 5 years was rated 2/M on blistering along the scribed mark, and 9 on over-all protection. After 5-1/2 years at Port Hueneme, it was rated 10.

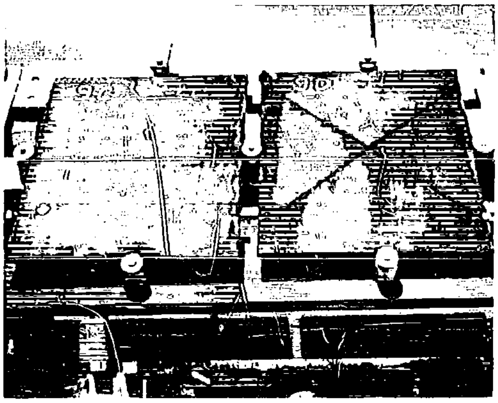
The protection to the unscribed panels was rated 8 at Kwajalein, 9 at Kaneohe, and 10 at Port Hueneme.

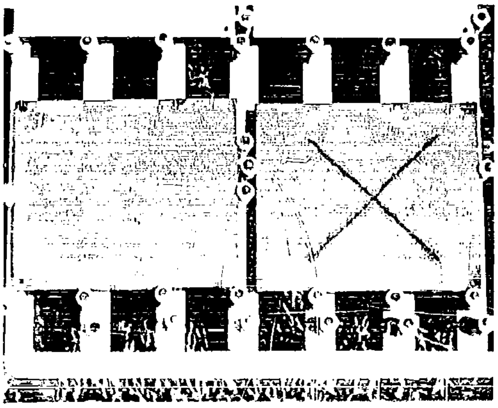
Light checking covered the surface of the neoprene at Kaneohe and Port Hueneme. This checking was not observed at Kwajalein.

Chalking of the coating was heavy and rated 2.



Kwajalein, 5-1/2 years


Kaneohe, 5 years

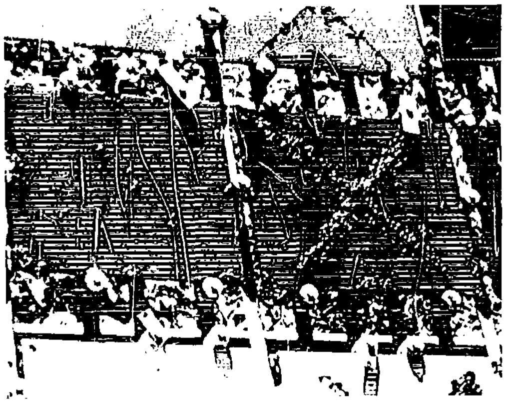

Port Hueneme, 5-1/2 years

System 11. Chlorinated Rubber-base Resin. This system (spray-applied) consisted of one coat of red lead varnish primer and five topcoats of chlorinated rubber. The total average thickness was 5.5 mils.

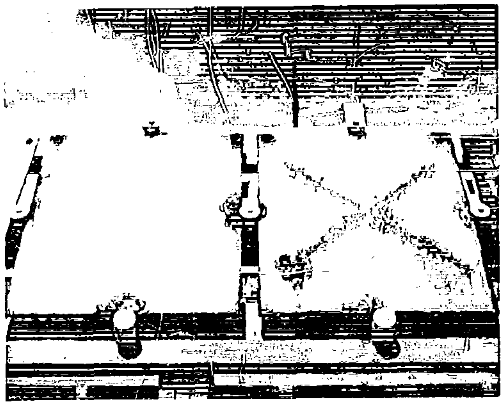
The chlorinated rubber coating failed completely because of blistering along the scribed mark, after 3 years at Kwajalein, and was removed from test. The blistering of the scribed panel, after 5 years at Kaneohe, was rated 2/D, and the protection given to the test panel was rated 7. After 5-1/2 years at Port Hueneme, no blistering had occurred.

On the unscribed panel at Kaneohe, blistering was occurring at points where slight pressure was applied by the porcelain insulators. The over-all rating was 9 at Kaneohe and 10 at Port Hueneme. The panel at Kwajalein was lost after three years of exposure, at which time the rating was 9.

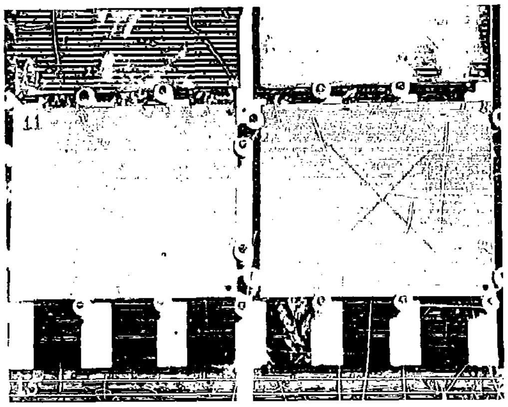
Chalking of this coating was rated 6.



Kwajalein, 3 years



Kaneohe, 5 years



Port Hueneme, 5-1/2 years

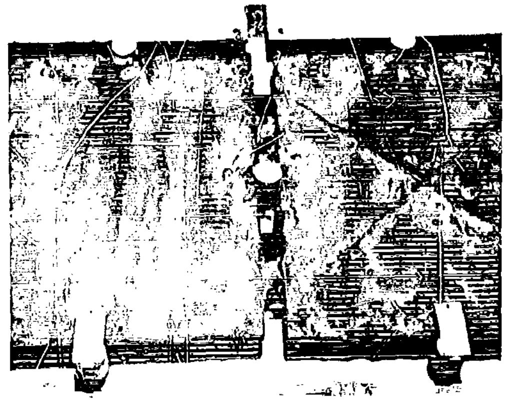
System 15. Cold-applied Coal Tar. This system consisted of one coat of coal-tar base (MIL-C-18480) and one brushed coat of coal-tar emulsion (MIL-C-15203). The total average thickness was 32 mils.

The scribed panel failed at Kwajalein after 4-1/2 years, because of blistering, and was removed from test. Blistering had occurred over about 60 percent of the plain surface and was rated 2/D along the scribed mark. After 5 years at Kaneohe, blistering along the scribed mark was rated 2/MD, and 10 after 5-1/2 years at Port Hueneme. Overall protection was rated 8 at Kaneohe and 10 at Port Hueneme.

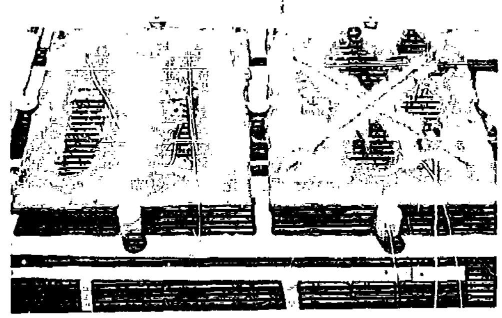
Protection to the unscribed panels was rated 7 at Kwajalein after 5-1/2 years, 9 at Kaneohe after 5 years, and 10 at Port Hueneme after 5-1/2 years.

There was shallow but not serious alligatoring over the entire surface of the test panels at Kaneohe and Port Hueneme. No alligatoring was present on the coating at Kwajalein.

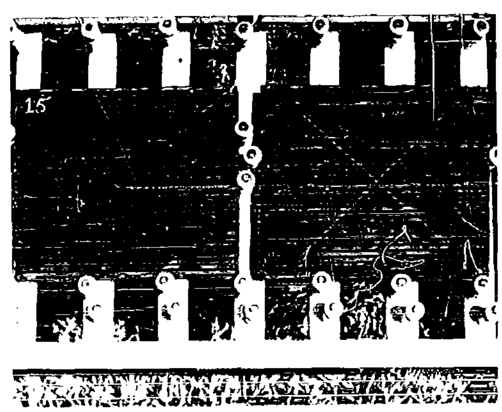
Chalking was light and was rated 8.



Kwajalein, 4-1/2 years



Kaneohe, 5 years

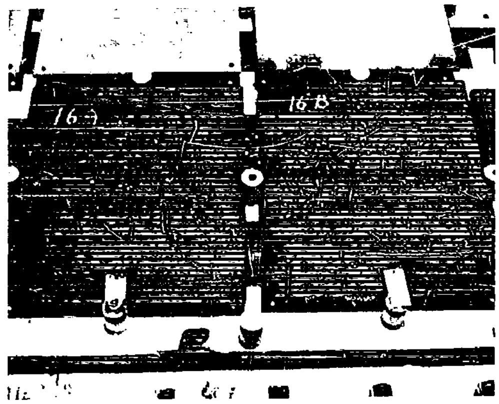


Port Hueneme, 5-1/2 years

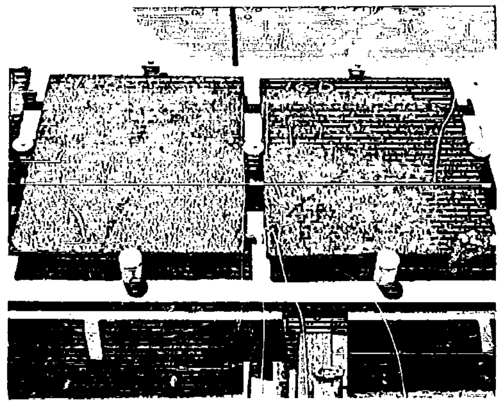
System 16. Mica-filled Asphalt Emulsion. This system (spray-applied) consisted of one coat of a wash primer (MIL-C-15328), one coat of a zinc chromate primer (JAN-P-735) and seven topcoats of the mica-filled asphalt emulsion. The total average thickness was 30.5 mils.

The general appearance of this coating was good, and the protection being given to both the scribed and unscribed test panels after 5 years exposure at Kaneohe and 5-1/2 years at Kwajalein and Port Hueneme was rated 10. Very light rusting had appeared in the scribed marks, but no blistering had occurred.

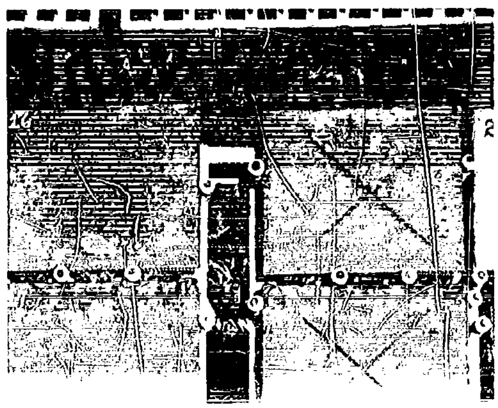
Chalking was very light and was rated 8.



Kwajalein, 5-1/2 years



Kaneohe, 5 years



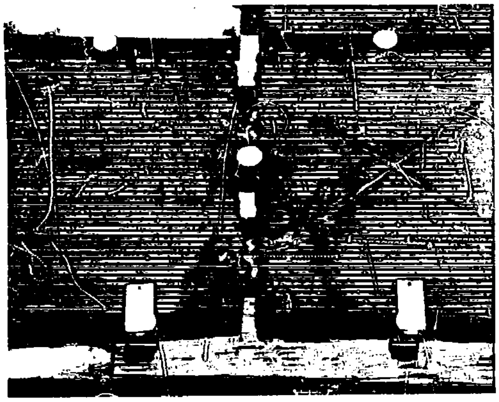
Port Hueneme, 5-1/2 years

System 17. Gilsonite Asphalt. The gilsonite asphalt was applied by brush; five coats gave a total average thickness of 125 mils.

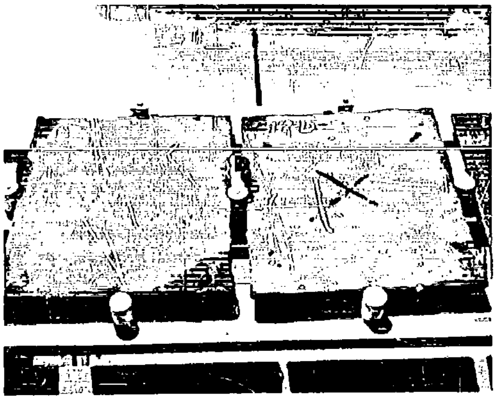
The scribed panel was removed from exposure after 4-1/2 years at Kwajalein. Blistering along the scribed mark and edges was rated 2/MD and more than 40 percent of the panel surface showed rusting and blistering. At Port Hueneme, after 5-1/2 years, the scribed panel was rated 10. At Kaneohe, after 5 years, the protection rating was 9 and blistering was rated 2/F.

The protec'' on to the unscribed panel at Kwajalein after 5-1/2 years was rated 7 because of large blisters (rated 2/D) around the edges. At Kaneohe after 5 years, the protection to the panel was rated 8 and edge-blistering 2/F; at Port Hueneme the over-all rating was 10 after 5-1/2 years.

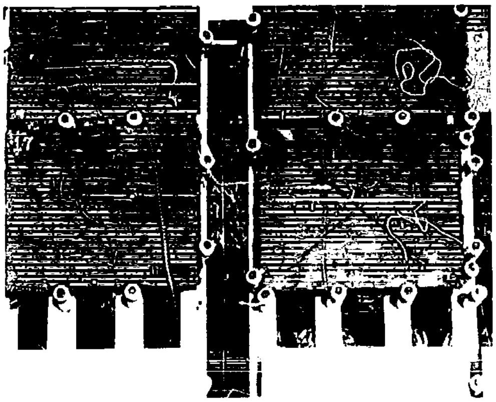
Chalking was moderate and was rated 6.



Kwajalein, 4-1/2 years



Kaneohe, 5 years

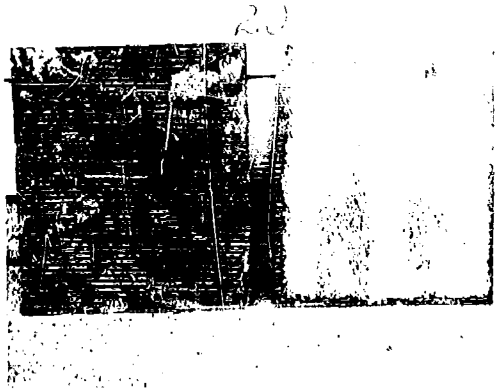


Port Hueneme, 5-1/2 years

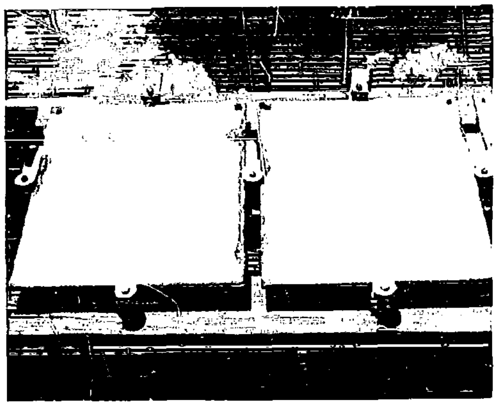
System 20. Flame-sprayed Zinc. Flame-sprayed zinc wire was applied to a total average thickness of 6 mils.

At Kwajalein, the protection after 2 years was rated 0, and the panels were removed from test. At Kaneohe after 5 years, the protection was rated 9 (edge-rusting), and at Port Hueneme, after 5-1/2 years, the rating was 10. No rusting was observed along the scribed mark at either Kaneohe or Port Hueneme.

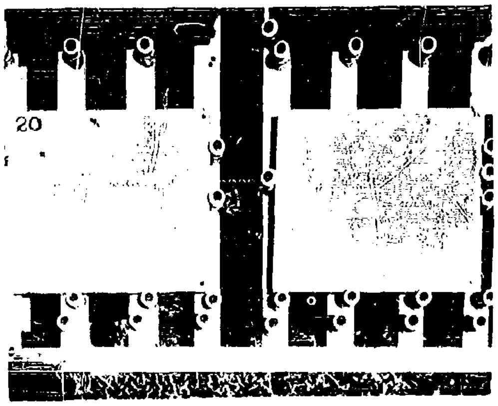
Zinc salts were present over most of the surface of the test panels.



Kwajalein, 2 years

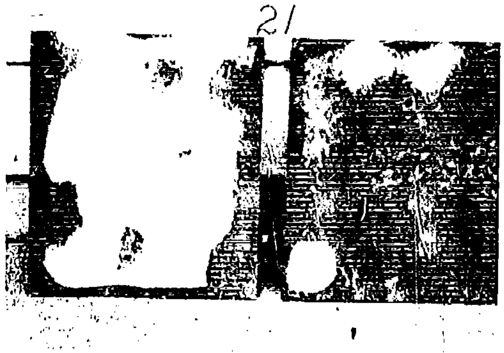


Kaneohe, 5 years



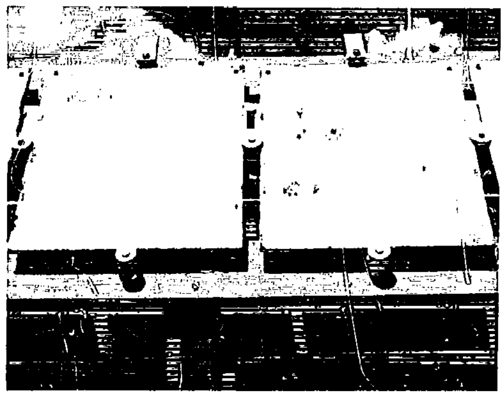
Port Hueneme, 5-1/2 years

System 21. Flame-sprayed Aluminum. To obtain good bonding of the aluminum to the steel test panels, it was necessary to apply a flame-sprayed steel wire bond coat. Flame-sprayed aluminum wire was applied over the steel bond coat. The average thickness of these metals was 0.5 mil for the steel bond and 4 mils for the aluminum metal, with a total for the system of 4.5 mils.



Kwajalein, 2 years

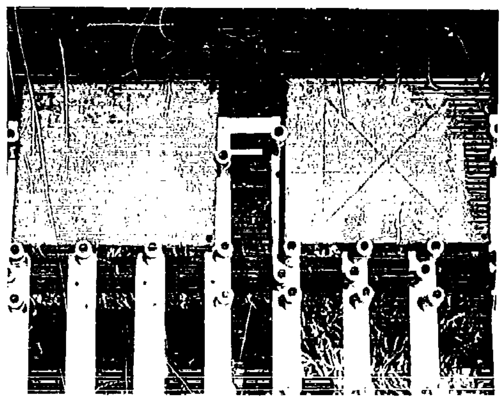
The aluminum-coated test panels at Kwajalein were removed from test after 2 years. They were showing rusting over most of their surface, and the scribed panel was almost completely rusted. After 5 years at Kaneohe, the scribed panel was showing rust and the corrosion products of aluminum over most of the surface and was rated 7; the unscribed panel was rated 9.



Kaneohe, 5 years

At Port Hueneme after 5-1/2 years, both panels were rated 10. A small amount of aluminum corrosion products covered the surface of these panels.

After four years exposure at Kaneohe, the back or underneath sides of the panels were covered with rust accumulation and the protection was rated 2. Rusting on the backs had not occurred at Port Hueneme; however, aluminum corrosion salts were present.



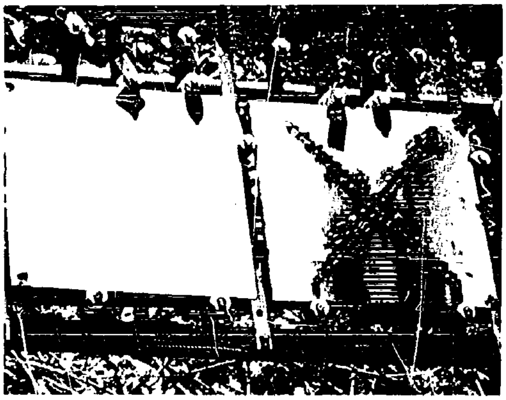
Port Hueneme, 5-1/2 years

System 23. Saran. This system (spray-applied consisted of six coats of Saran lacquer (Formula 113/49), which gave an average total thickness of 7 mils.

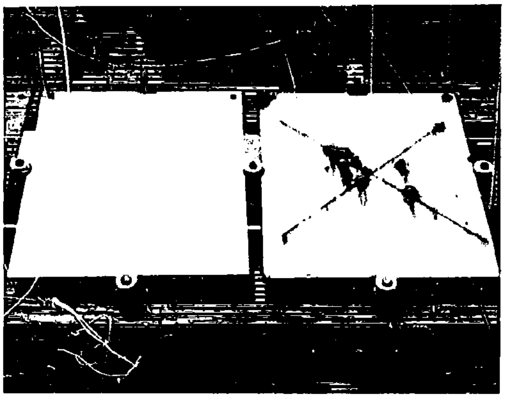
The scribed panel coated with Saran failed after 3 years at Kwajalein because of blistering along the scribed mark. At Kaneohe after 5 years, blistering along the scribed mark and edges was rated 2/MD, and at Port Hueneme after 5-1/2 years, the blistering was rated 4/M.

The protection to the unscribed panel at Kwajalein after 5-1/2 years was rated 8 because of slight blistering at edges and pinhole rusting over the surface. No blistering had occurred on the unscribed panel at Kaneohe; but many very small pinhole rust spots were present, and the panel protection was rated 9. At Port Hueneme, the panel was rated 10 after 5-1/2 years.

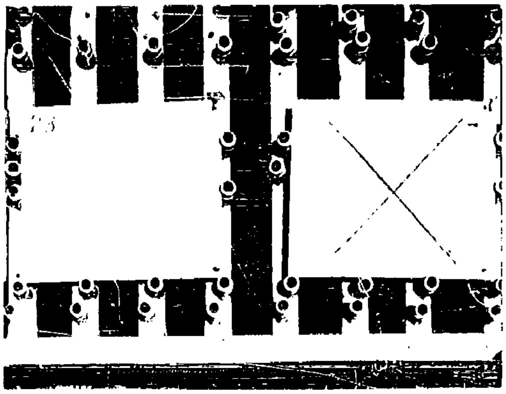
Chalking was moderate and rated 6.



Kwajalein, 3 years



Kaneohe, 5 years



Port Hueneme, 5-1/2 years

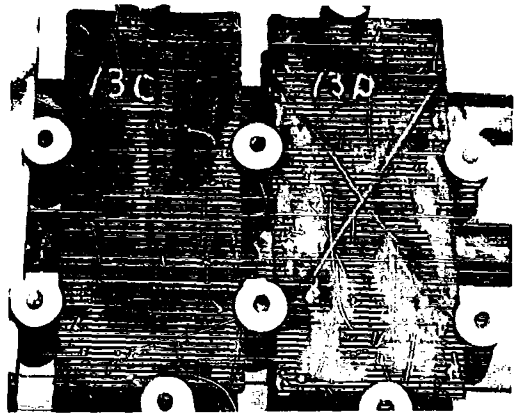
SERIES II. COATINGS EXPOSED 2-1/2 TO 4 YEARS

System 13. Cold-applied Coal Tar. This system consisted of four brushed coats of cold-applied coal-tar-base coating (MIL-C-18480) and two brushed coats of coal-tar emulsion (MIL-C-15203). The total average thickness was 35 mils.

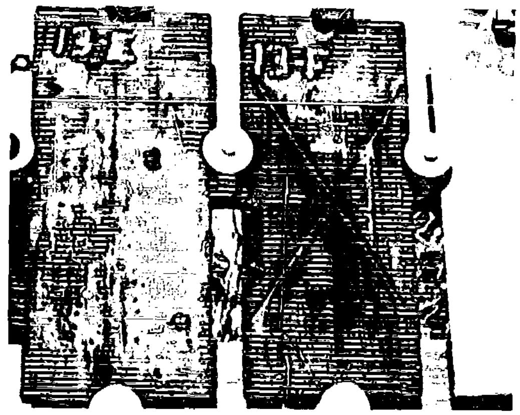
At Kwajalein after 3-1/2 years, there was blistering along the scribed mark of the scribed panel and at the edges of both panels. Protection of the scribed panel was rated 8 and the unscribed panel 9. Blistering along the scribed mark was rated 2/D, and at the edges 2/F.

This system has been on exposure at Port Hueneme for 4 years and for 2-1/2 years at Kaneohe and was rated 10 on protection. No alligatoring, blistering, or undercutting had occurred.

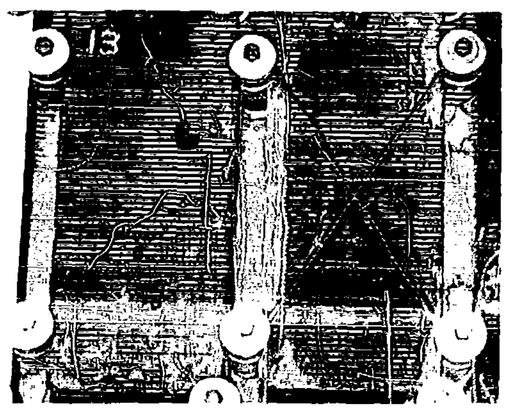
Chalking was moderate and rated 6.



Kwajalein, 3-1/2 years



Kaneohe, 2-1/2 years



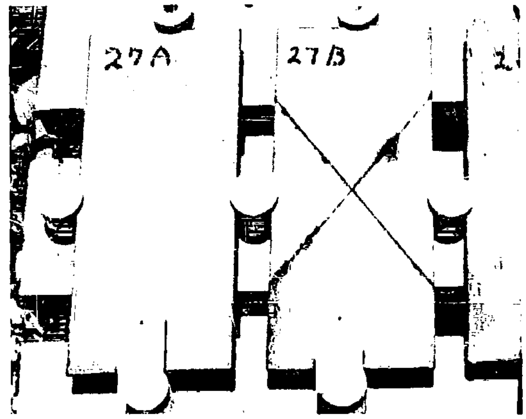
Port Hueneme, 4 years

System 27. <u>Chlorosulfonated Polyethylene</u>. This system consisted of two brushed coats of a red lead iron-oxide vinyl primer and five brushed coats of a catalyzed chlorosulfonated polyethylene. The total average thickness of this system was 8.5 mils.

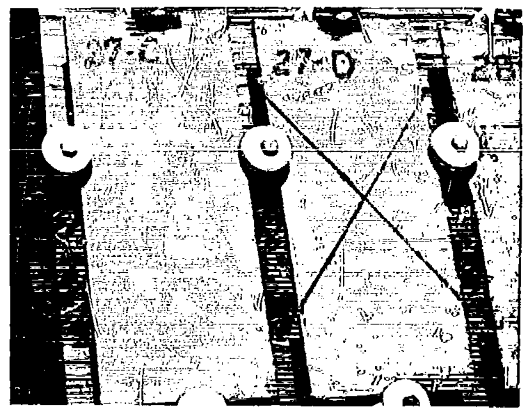
This system has blistered considerably along the scribed mark and was rated 4/MD after 2-1/2 years at Kwajalein. Except along the scribed mark, the protection to both panels was rated 10.

At Port Hueneme and at Kaneohe after 2-1/2 years the scribed and unscribed panels were rated 10.

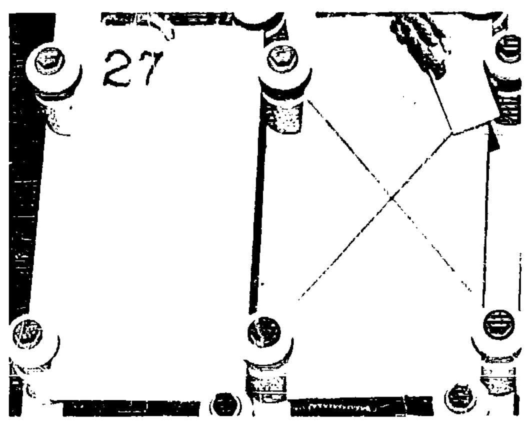
Chalking was moderate and rated 6.



Kwajalein, 2-1/2 years



Kaneohe, 2-1/2 years



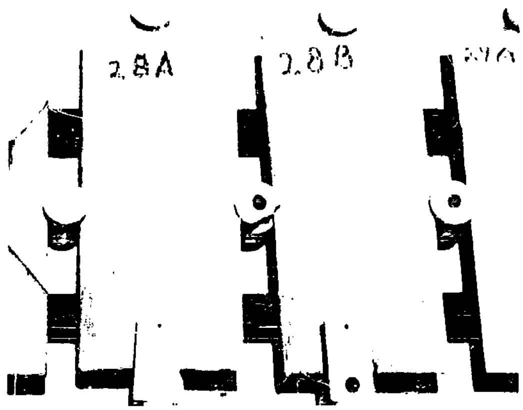
Port Hueneme, 2-1/2 years

System 28. Zinc-filled Modified Epoxy. This system consisted of three brushed coats of a catalyzed zinc-filled modified epoxy resin. The total average thickness was 7.5 mils.

After 2-1/2 years at Kwajalein, white zinc salts had formed over about 10 percent of the surface; however, no rusting had occurred along the scribed mark or on the unscribed surface and the overall protection was rated 10. Zinc salts had formed at minute blisters; blistering over the surface of the two panels was rated 8/M.

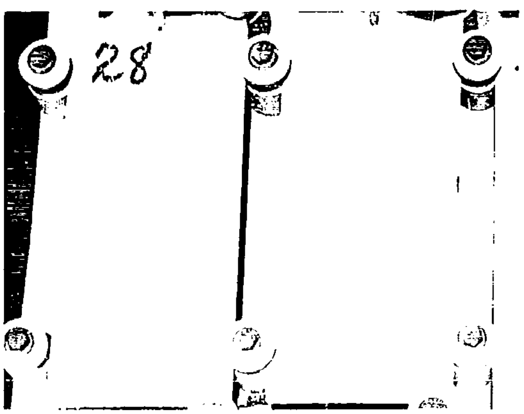
At Kaneohe and Port Hueneme after 2-1/2 years, surface weathering had produced some zinc salts. But no blistering had occurred, and the coating was rated 10.

No chalking was present on this coating.



Kwajalein, 2-1/2 years

Kaneohe, 2-1/2 years



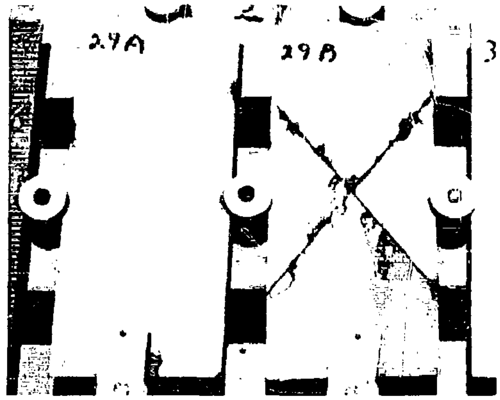
Port Hueneme, 2-1/2 years

System 29. Epoxy. This system consisted of one brushed primer coat of catalyzed epoxy and two brushed topcoats of catalyzed epoxy. The total average thickness was 11 mils.

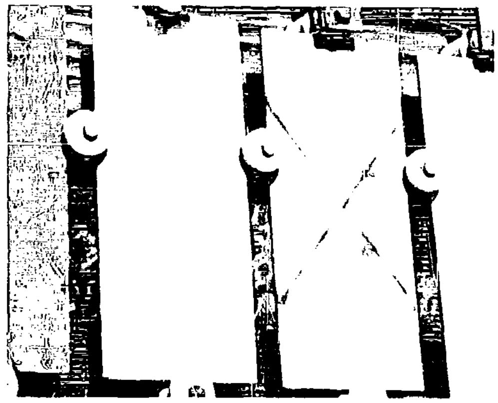
After 2-1/2 years at Kwajalein, there was blistering along the scribed mark, and the coating was rated 2/D. At Kaneohe after 2-1/2 years, blistering of the scribed panel was rated 4/F. No blistering or rusting had occurred after 2-1/2 years at Port Hueneme, and the coating on the scribed panel was rated 10.

The protection to the unscribed panels was rated 9 at Kwajalein and 10 at Kaneohe and Port Hueneme.

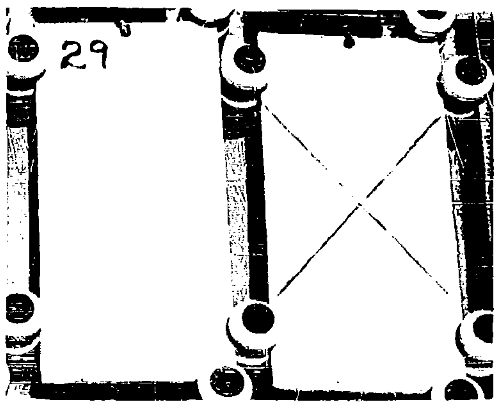
Chalking was very light and rated 8.



Kwajalein, 2-1/2 years



Kaneohe, 2-1/2 years



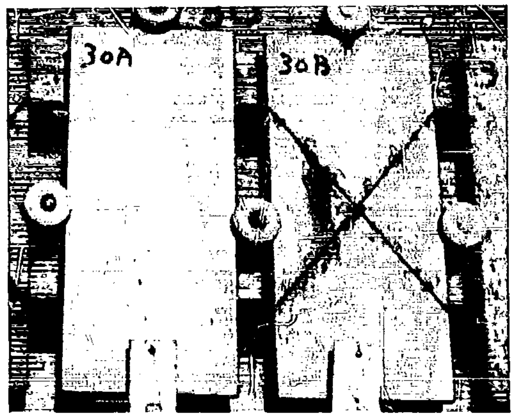
Port Hueneme, 2-1/2 years

System 30. Aluminum-pigmented Urethane. This system consisted of three brushed coats of a catalyzed red lead urethane primer, one sprayed coat of catalyzed urethane intermediate coat and four sprayed topcoats of catalyzed aluminum-pigmented urethane topcoat. The total average thickness was 5 mils.

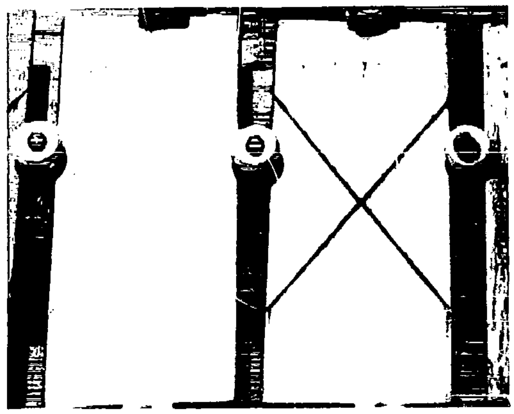
Blistering of this coating along the scribed mark was rated 2/D after 2-1/2 years at Kwajalein. The protection to the remaining surfaces was rated 10. At Kaneohe after 2-1/2 years, this coating was rated 8/F for blistering on the scribed panel and 10 for over-all protection. At Port Hueneme after 2-1/2 years, blistering on the scribed panel was rated 6/D, and over-all protection was rated 10.

The protection of the unscribed panels at each of the three test sites was rated 10.

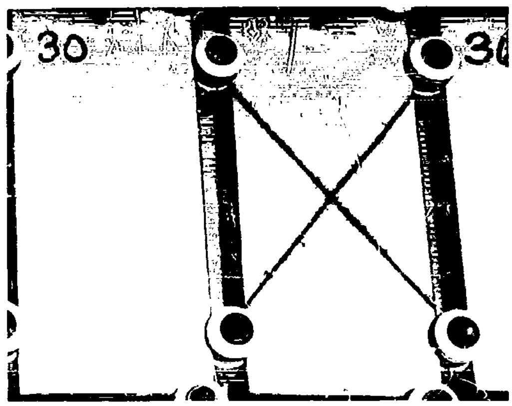
Chalking was rated 10.



Kwajalein, 2-1/2 years



Kaneohe, 2-1/2 years



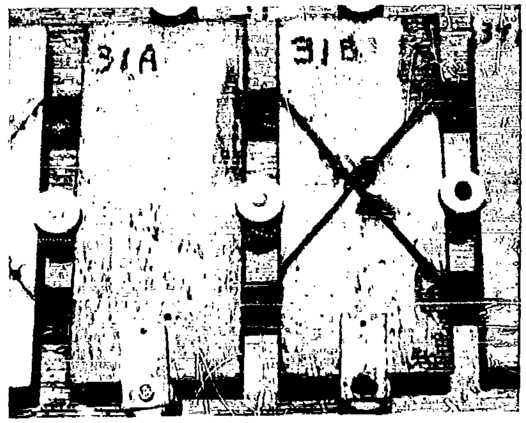
Port Hueneme, 2-1/2 years

System 31. Aluminum-pigmented Epoxy Tar. This system consisted of one brushed primer coat of catalyzed epoxy tar, two brushed intermediate coats of catalyzed epoxy tar, and one brushed topcoat of aluminum-pigmented epoxy tar. The total average thickness was 23.0 mils.

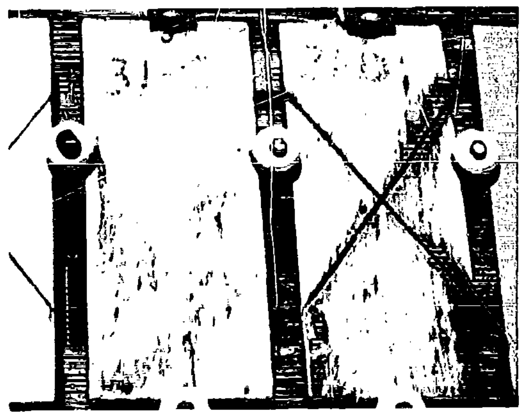
The scribed panel at Kwajalein after 2-1/2 years was rated 2/F on blistering along the scribed mark and 9 for over-all protection. The scribed panel at Kaneohe and Port Hueneme after 2-1/2 years was rated 10.

The unscribed panel at all three test sites was given a rating of 10.

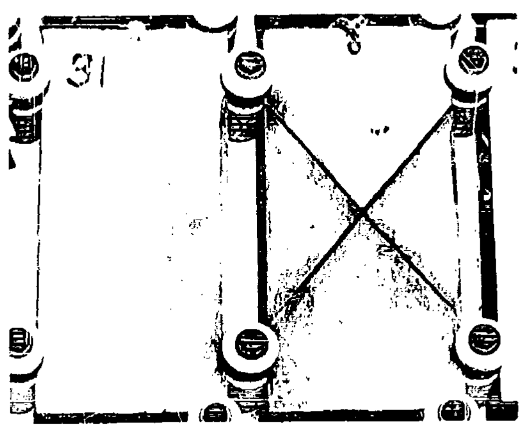
No chalking was present at this time.



Kwajalein, 2-1/2 years



Kaneohe, 2-1/2 years



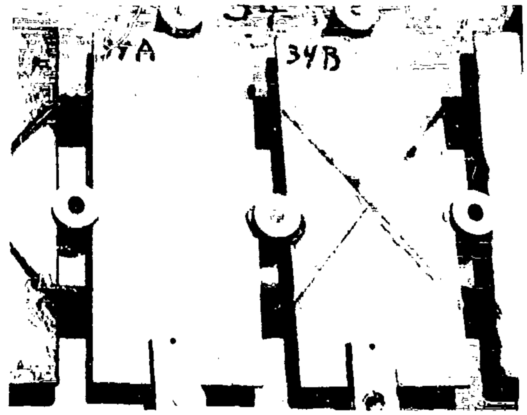
Port Hueneme, 2-1/2 years

System 34. Epoxy. This system (spray-applied) consisted of one primer coat of catalyzed epoxy, one intermediate coat of catalyzed epoxy, and five topcoats of catalyzed epoxy. The total average thickness was 7 mils.

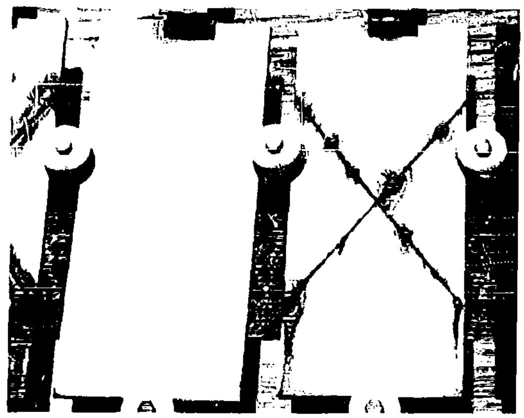
Blistering of the scribed panel after 2-1/2 years at Kwajalein extended the full length of the scribed mark and was rated 6/D. At Kaneohe after 2-1/2 years, blistering along the scribed mark was rated 4/MD, and at Port Hueneme after 2-1/2 years, the rating was 8/D. The over-all protection to the scribed panel was rated 9 at each test site.

The unscribed panel was rated 9 on over-all protection at Kwajalein (because of an edge blister), and was rated 10 at Kaneohe and Port Hueneme.

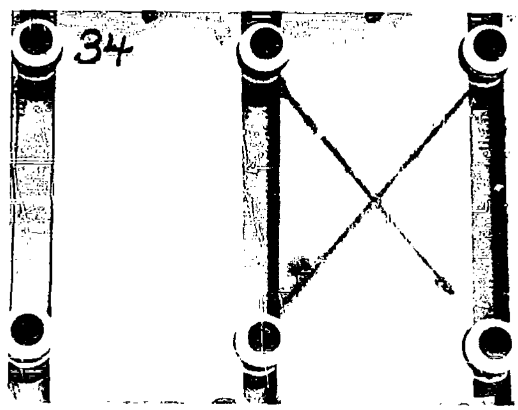
Chalking was moderate and rated 6.



Kwajalein, 2-1/2 years



Kaneohe, 2-1/2 years



Port Hueneme, 2-1/2 years

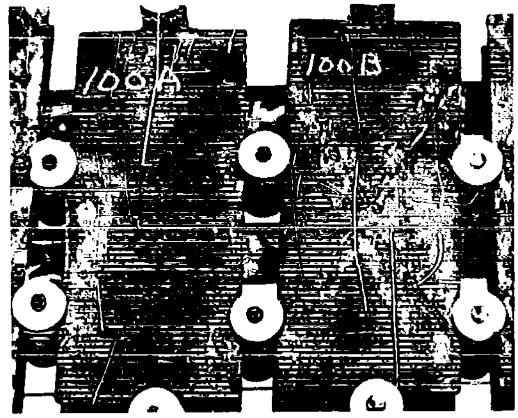
System 100. Coal-tar Epoxy. This system consisted of two brushed coats of catalyzed coal-tar epoxy. The total average thickness was 14 mils.

After 3 years at Kwajalein, severe blistering had occurred along the scribed mark, and it was rated 2/D; protection was rated 8.

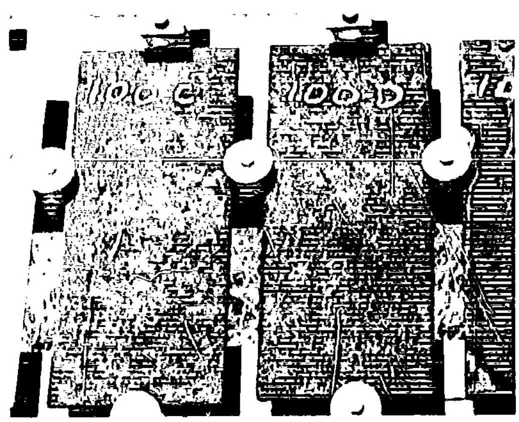
Some edge blistering had occurred on the unscribed panel, and the protection was rated 9.

After 2-1/2 years at Kaneohe and 3-1/2 years at Port Hueneme, this coating showed no signs of failure and was rated 10.

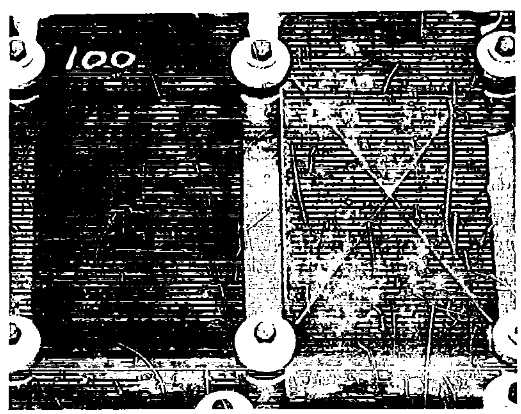
Chalking was moderate and rated 6.



Kwajalein, 3 years



Kaneohe, 2-1/2 years



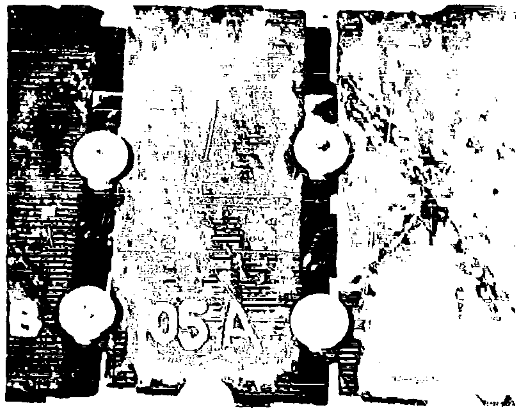
Port Hueneme, 3-1/2 years

System 105. Neoprene. This system consisted of two brushed primer coats of synthetic rubber and two brushed topcoats of catalyzed neoprene. The total average thickness was 11.5 mils.

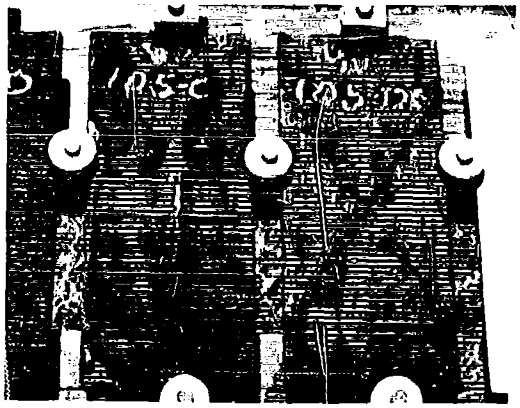
The scribed panel failed after 2-1/2 years at Kwajalein. Blistering along the scribed mark was rated 2/D; blistering at the edges reduced the protection to a rate of 6, and the panel was removed from test. The condition of the coating on the scribed panel at Kaneohe after 2-1/2 years exposure was slightly better than that at Kwajalein, and the protection was rated 9. At Port Hueneme after 3-1/2 years, rusting was occurring along the scribed mark, but no blistering had occurred and protection was rated 10.

The protection given to the unscribed panel at the various test sites was rated 8 at Kwajalein after 3 years, 9 at Kaneohe after 2-1/2 years, and 10 at Port Hueneme after 3-1/2 years.

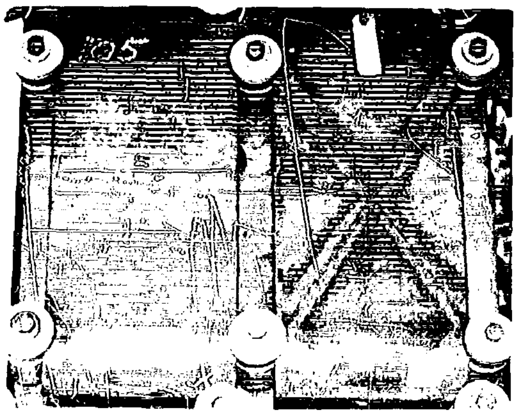
Chalking was heavy and was rated 2.



Kwajalein, 2-1/2 years



Kaneohe, 2-1/2 years



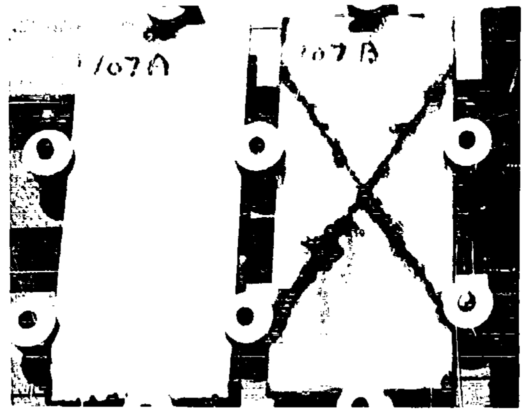
Port Hueneme, 3-1/2 years

System 107. Aluminum-pigmented Chlorinated Rubber. This system consisted of one brushed primer coat of red lead chlorinated rubber and three sprayed top-coats of aluminum-pigmented chlorinated rubber. The total average thickness of this system was 5.5 mils.

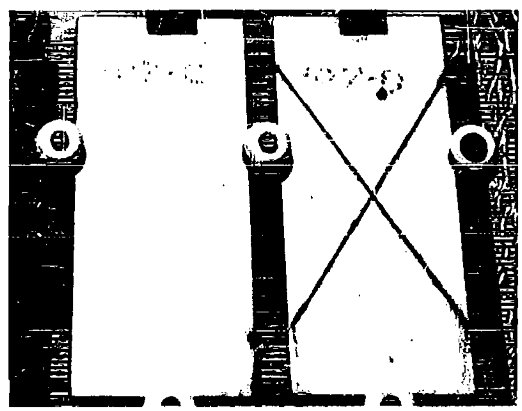
Blistering of the scribed panel at Kwajalein after 3 years was dense and was rated 2/D. Rusting along the scribed mark was heavy. The over-all protection was rated 8. Damage was confined to the scribed area. Blistering of the scribed panel at Kaneohe after 2-1/2 years was light and rated 2/F; the over-all protection was rated 10. At Port Hueneme after 3-1/2 years, the coating was rated 10.

The protection of the unscribed panel at Kwajalein was rated 9 because of edge blistering and rusting; at Kaneohe and Port Hueneme, the rating was 10.

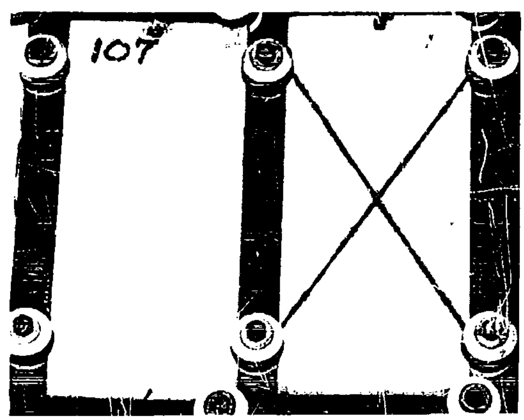
No chalking was observed and rated 10.



Kwajalein, 3 years



Kaneohe, 2-1/2 years



Port Hueneme, 3-1/2 years

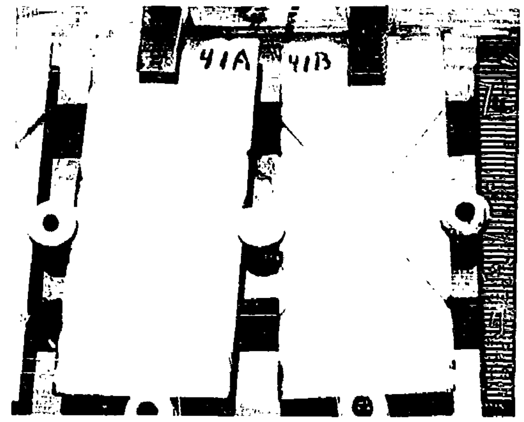
SERIES III. COATINGS EXPOSED 1-1/2 TO 2-1/2 YEARS (PORT HUENEME AND KWAJALEIN ONLY)

System 41. Epoxy. This system (spray-applied) consisted of one primer coat of catalyzed epoxy, one intermediate coat of catalyzed epoxy, and one topcoat of catalyzed epoxy. The total average thickness was 6 mils.

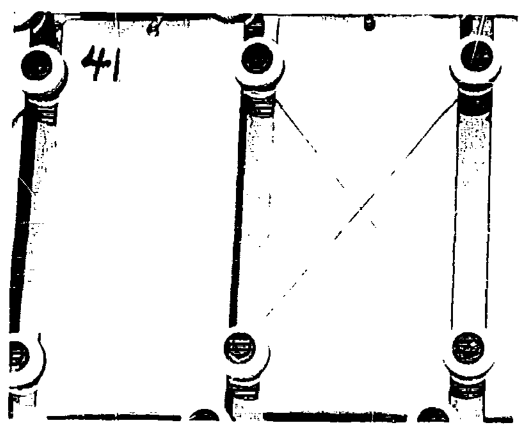
After 1-1/2 years at Kwajalein, the scribed panel showed dense blistering along the scribed mark, rated 6/D; over-all protection was rated 9. After 2-1/2 years at Port Hueneme, blistering of the scribed panel was light and rated 8/M; protection was rated 10.

The protection of the unscribed panel was rated 9 at Kwajalein because of blistering and rusting at the edges; no failure of the coating was observed at Port Hueneme, and the coating was rated 10.

Chalking was considerable and was rated 4.



Kwajalein, 1-1/2 years



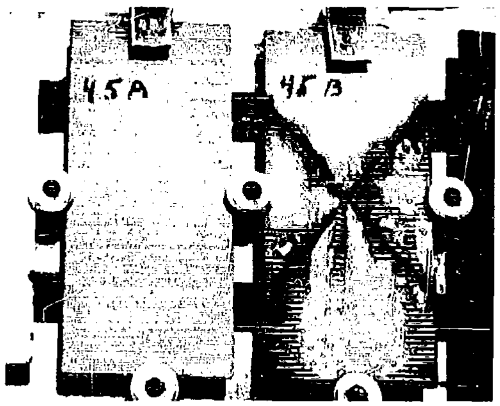
Port Hueneme, 2-1/2 years

System 45. Urethane. This system (spray-applied) consisted of one coat of iron-oxide vinyl primer and two topcoats of catalyzed urethane. The total average thickness was 6.5 mils.

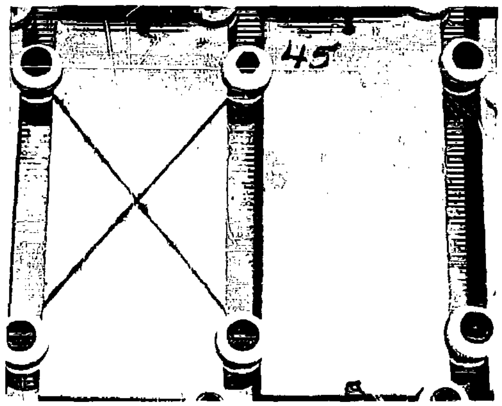
The scribed panel at Kwajalein after 1-1/2 years had dense blistering along the scribed mark, rated 2/D. There was heavy rusting in the scribed mark, and the overall protection was 7. After 2 years at Port Hueneme no blistering had occurred, and this panel was rated 10.

The unscribed panel had received excellent protection at both test sites and was rated 10.

Chalking was light and rated 8.



Kwajalein, 1-1/2 years



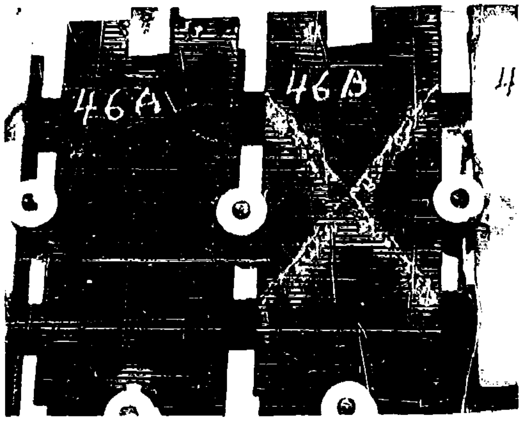
Port Hueneme, 2 years

System 46. Urethane Coal Tar. This system consisted of two brushed coats of a catalyzed urethane coal tar. The total average thickness was 8 mils.

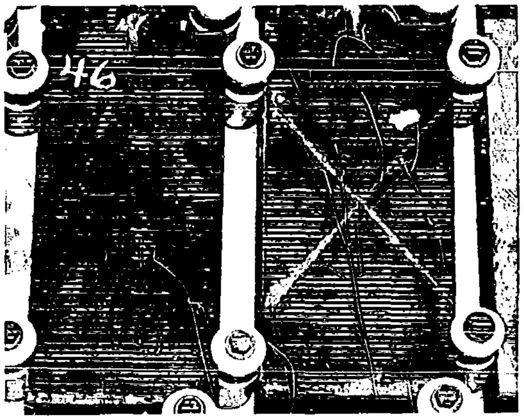
After 1-1/2 years at Kwajalein, the over-all protection of the scribed panel was rated 8. Blistering along the scribed mark was dense and rated 4/D. At Port Hueneme after 2 years, blistering of the scribed panel was light and rated 8/F. The over-all protection to the panel was rated 9.

The protection of the unscribed panel was rated 10 at both test sites.

Chalking was rated 6.



Kwajalein, 1-1/2 years



Port Hueneme, 2 years

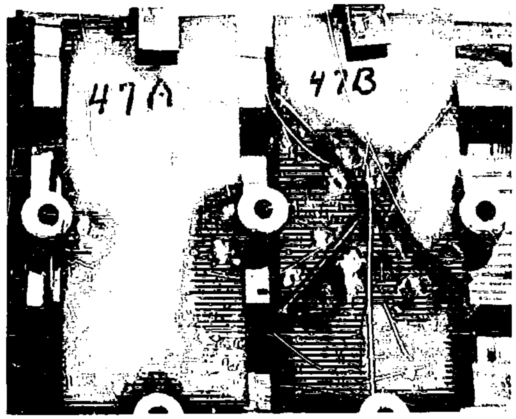
System 47. Urethane. This system consisted of one brushed coat of a wash primer and three sprayed topcoats of a catalyzed urethane. The total average thickness was 6.5 mils.

The scribed panel at Kwajalein failed after 1-1/2 years and at Port Hueneme after 2 years and was removed from test. Blistering at Kwajalein was rated 2/D. At Port Hueneme there was no blistering but the coating flaked over 50 percent of the surface of the panel.

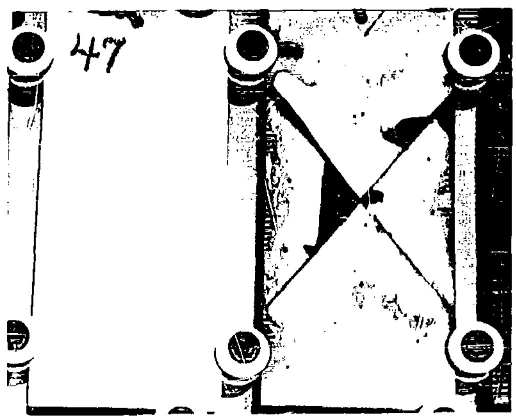
The unscribed panel at Port Hueneme had received excellent protection, rated 10; the panel at Kwajalein had blistered and rusted at the edges and was rated 8.

Chalking was rated 6.

This coating was applied directly over a wash primer. This type of primer does not appear suitable for urethane.



Kwajalein, 1-1/2 years



Port Hueneme, 2 years

DISCUSSION AND COMPARISON OF COATINGS OF SIMILAR GENERIC TYPE

Bituminous-base Coatings

Asphaltic Coating

System 16 (mica-filled asphalt emulsion over zinc chromate primer and wash primer) has been the most outstanding system on exposure at the three test sites. Of all the coating systems tested, this has given the best protection to steel panels. No sign of failure has appeared on the scribed or unscribed panel after 5-1/2 years of exposure in the three marine atmospheres. The asphaltic-base coating, System 17, failed at the scribed mark and edges after 4-1/2 years at Kwajalein, and the unscribed panel was rated 7 because of numerous large blisters near the edges of the panel.

Coal-tar-base Coating (MIL-C-18480; MIL-C-15203)

Two coal-tar-base systems were exposed at the three test sites; (1) System 13, which contained two coats of coal-tar-base emulsion (MIL-C-15203) over the cold-applied coal tar (MIL-C- 18480); and (2) System 15, which had only one coat of the emulsion topcoat. System 13 has given slightly better protection to the test panels than System 15 and has shown no signs of alligatoring after four years at Port Hueneme and 2-1/2 years at Kaneohe. Alligatoring first appeared on coating System 15 between three to four years of exposure at Kaneohe and Port Hueneme. No alligatoring had occurred to either system in the damp marine atmosphere at Kwajalein after 5-1/2 years for System 15 and 3-1/2 years for System 13.

Inorganic-base Zinc Coating

The inorganic-base zinc coating, System 4, has given good protection for 5-1/2 years, but initial signs of failure have appeared at Kwajalein and Kaneohe. Numerous red rust specks have appeared at pinhole breaks over much of the panel surface at Kwajalein. This occurred to a lesser extent at Kaneohe, but not at all at Port Hueneme. The scribed area has received excellent protection.

Vinyl

A vinyl system, a vinyl mastic system, and an aluminum-pigmented vinyl system are under test at the three test sites. Each of these three systems failed on the scribed panel at Kwajelein, after 4-1/2 years of exposure, because of blistering at the scribed mark and edges. After 5-1/2 years at Kwajalein, the aluminum-pigmented vinyl (System 1) and vinyl mastic (System 6) were given a protection rating of 9 for

the unscribed panel, and the vinyl (System 5) was rated 8. The aluminum vinyl has given better protection to the edges than has the vinyl or vinyl mastic at Kwajalein. Blistering and rusting have appeared at pinhole breaks in the unscribed panel surfaces coated with the vinyl system.

In the less corrosive marine atmosphere at Kaneohe, where rusting of the exposed steel is not as severe, the vinyl mastic gave better protection than did the vinyl system or the aluminum-pigmented vinyl system.

At Port Hueneme, the three systems have given equal protection to the steel panels.

Synthetic Rubber Coatings

Neoprene

Two neoprene systems (9 and 105) were placed on exposure at the three test sites. These coatings were brush-applied as suggested by the manufacturers; no difficulty was encountered. System 9 provided a coating thickness of 31.0 mils, and System 105 a thickness of 11.5 mils. As expected, the thicker coat of System 9 gave better protection. After 5-1/2 years at Kwajalein, about 80 percent of the panel surface was protected; whereas, the 11.5-mil coating of System 105 failed at Kwajalein after 2-1/2 years. In the severe marine atmosphere of Kwajalein, the neoprene was very susceptible to blistering and undercutting at breaks in the coating.

Chlorosulfonated Polyethylene (Hypalon)

This coating (System 27), applied to a thickness of 8.5 mils, has been on exposure for about 3 years. Compared to the neoprene coating (System 105), the chlorosulfonated polyethylene had superior resistance to blistering after 3 years exposure at the three test sites. After 3 years at Kwajalein, there was a greater degree of blistering along the scribed mark of the neoprene system (9) than in System 27. The over-all protection given to the unscribed panel after 3 years at Kwajalein was rated 9 for System 9, 8 for System 105, and 10 for System 27.

After 3 years exposure, System 27 gave better protection to the steel test panels than did the neoprene coatings.

Chlorinated Rubber

System 107 (aluminum-pigmented chlorinated rubber) gave better protection to the test panels at Kwajalein for 3 years than did System 11 (chlorinated rubber). After 2-1/2 years at Kaneohe, System 11 blistered more at the scribed mark than did System 107. At Port Hueneme a rating of 10 was assigned to both System 11 after 5-1/2 years and System 107 after 3-1/2 years, for the scribed and unscribed panels.

Epoxy-base Coatings

Five catalyzed epoxy systems were exposed at the three test sites. Four were epoxy, and one was a zinc-filled modified epoxy.

The four epoxy systems (3, 29, 34, and 41) showed severe blistering at mechanical breaks in the coating, especially at the scribed mark and edges. The blistering along the scribe was rated dense at Kwajalein for three of these systems after 3 years exposure and for System 41 after 1-1/2 years exposure. The protection given to the unscribed test panels by Systems 3 and 34 is slightly superior to the protection given by Systems 29 and 41. System 34 has given slightly better protection at the scribed mark at Kwajalein for three years than have Systems 3, 29, and 41.

The fifth, or zinc-filled modified epoxy coating (System 28), has given excellent protection to the scribed and unscribed panel for 3 years at the three test sites. No rusting has occurred along the scribed mark or along the edges. However, the presence of zinc salts on the surface, especially at Kwajalein, gives an indication of coating breakdown. Of the epoxy systems tested, System 28 has given the best protection.

Urethane Coatings

Three urethane coatings were exposed at the three test sites.

Urethane (System 47) was applied over a wash primer. The scribed panel failed because of undercutting in the second year of exposure at both Kwajalein and Port Hueneme. Also, this system is giving poor protection to the unscribed panel at Kwajalein. A wash primer does not appear to be a satisfactory single primer for the urethane coating. The urethane in System 45 was the same urethane as that in System 47, but it was applied over iron-oxide vinyl primer. This system also is giving poor protection along the scribed mark at Kwajalein after 1-1/2 years, but good protection was observed along the scribed mark at Port Hueneme after two years.

System 30 is an all-urethane system, the primer being a urethane red lead and the topcoat an aluminum-pigmented urethane. This system has shown no tendency to undercut after about three years at the three test sites. Although blistering has occurred along the scribed marks of the panels coated with System 30, this system has given better protection to the scribed panel than has System 45.

Both System 30, after 3 years, and System 45, after 1-1/2 years, have given excellent protection to the unscribed panels.

Epoxy Tar and Urethane Tar Coatings

An aluminum-pigmented epoxy tar (System 31) and an epoxy tar (System 100) have been exposed three years at Kwajalein. The aluminum-pigmented coating has evidenced less blistering at the scribed mark and has given better over-all protection to steel test panels than has System 100 at Kwajalein. Both coatings were rated 10 at both Kaneohe (2-1/2 years) and Port Hueneme (3-1/2 years) and have given comparable protection.

After 1-1/2 years at Kwajalein a urethane tar (System 46) had failed to the same degree at the scribed mark as had the epoxy tar (System 100) after 3 years at this test site.

The epoxy tar (System 100) has given better protection to the unscribed panel at Port Hueneme for 3-1/2 years than has the urethane tar (System 46) for a period of only 2 years.

The thicker 23-mil coating of System 31, gave better protection than did the 14-mil thickness of System 100 or the 8-mil thickness of System 46.

Metalized Coatings

Zinc and Aluminum (Unsealed)

The flame-sprayed zinc (System 20) and aluminum (System 21) failed at Kwajalein within two years. At that time the failure of the zinc coating was nearly complete, and the aluminum-coated panel showed rust over most of its surface. After four years at Kaneohe, the back or underneath side of the aluminum coating was covered with rust and was rated 2 on protection. The underneath side of the metalized panels at Port Hueneme showed no rusting.

The white corrosion salts of aluminum were present over much of the top surface of the panels at Kaneohe after five years, but the salts were present at Port Hueneme to only a limited degree.

The zinc coating has given slightly better over-all protection than the aluminum coating, possibly because the thickness was slightly greater.

Miscellaneous Coatings

1. Phenolic mastic (System 7)
2. Furan resin (System 8)
3. Saran resin (System 23)

After 5-1/2 years at Kwajalein, blistering on the scribed panels of Systems 7 and 8 was rated medium dense, the largest blisters being about one inch in diameter. Systems 7 and 8 have given equal protection to the panels at Kaneohe and Port Hueneme, but System 8 gave slightly better protection at Kwajalein.

System 23 has given good protection to over 80 percent of the surface of the unscribed test panel for 5-1/2 years at Kwajalein. Failure of the coating along the scribed mark occurred after 3 years. Pinhole rusting has appeared over the surface of the Saran coating after 5-1/2 years; however, protection was rated 8. System 8 (furan resin) was rated 9 after 5-1/2 years at Kwajalein, and it gave slightly better protection than did Saran (System 23). Phenolic mastic (System 7) gave equal protection to that of Saran.

DISCUSSION OF ENVIRONMENT

It was found that the three marine atmospheric environments used in the cooperative studies of protective coatings would be rated in the following order of severity: (1) Kwajalein, (2) Kaneohe, and (3) Port Hueneme. Table I lists protection after 5-1/2 years, and Table II classifies coating system protection. Using the 10 to 0 rating system for both scribed and unscribed steel test panels, the corrosive environment at Kwajalein was rated, after 5 years of exposure for many of the coatings, two figures lower than at Kaneohe, and Kaneohe was often one figure lower than Port Hueneme. The scribed panel coated with Saran (System 23) developed a dense accumulation of blisters along the scribed mark at Kwajalein during 3 years of exposure; at Kaneohe only initial failure along the scribed mark and edges had occurred during 5 years; but at Port Hueneme, very little coating failure was found after 5-1/2 years. Consequently, for determining the protection given to steel test panels by a coating system in a marine atmosphere, the environment at Kwajalein is much more corrosive than that of Kaneohe or Port Hueneme. For example, at Kwajalein after 5-1/2 years, 10 of the 15 coating systems of Series I were rated 8 or better on the unscribed panel; only 2 systems were rated 8 or better on the scribed panel because of blistering and rusting at the scribe. At Kaneohe, 14 of these coatings on unscribed panels were rated 9 or better, and the remaining one was rated 8. At Port Hueneme all 15 coatings were rated 9 or better. On the scribed panels, 3 coatings had failed after 5 years at Kaneohe, and none had failed at Port Hueneme. A relocation of the test racks at Kaneohe and Port Hueneme, to increase their exposure to the ocean spray, would increase the severity of these two sites in promoting coating failure. At Kaneohe the racks can be moved about 100 yards closer to the surf and at Port Hueneme about 100 feet closer to the surf.

Table I. Protection Rating after 5-1/2 Years
(except as noted)

Rating	Unscribed Panels			Scribed Panels		
	Kw*	Ka*	PH*	Kw	Ka	PH
	System Number			System Number		
9 to 10	1 3 6 8 16	1 9 3 11 4 15 5 16 6 20 7 21 8 23	1 11 3 15 4 16 5 17 6 20 7 21 8 23 9	16	4 9 5 16 6 17 7 20	1 11 3 15 4 16 5 17 6 20 7 21 8 23 9
8	4 9 5 23 7	17		4	1 3 15 23	
7 or less (failed)	11[1] 15 17 20[2] 21[2]			1[3] 11[1] 3[1] 15[3] 5[3] 17[3] 6[3] 20[2] 7 21[2] 8 23 9	8 11 21	

1 Failed after 3 years; 2 Failed after 2 years; 3 Failed after 4-1/2 years

* Kw = Kwajalein; Ka = Kaneohe; PH = Port Hueneme

Table II. Classification of Coating System Protection

Series	Group 1 (No failure on either panel)		Group 2 (Superior to selected standard)		Group 3 (Equal to selected standard)		Group 4 (Inferior to selected standard)	
	System	Type	System	Type	System	Type	System	Type
I (exposed 5 to 5-1/2 years)	16	Mica-filled asphalt emulsion	1	Aluminum-pigmented vinyl	3	Epoxy	11	Chlorinated rubber
			4	Zinc-dust-pigmented inorganic silicate	5	Vinyl	15	Cold-applied coal tar
			6	Vinyl mastic	7	Phenolic mastic	17	Gilsonite asphalt
			8	Furan resin mastic	9	Neoprene	20	Flame-sprayed zinc
					23*	Saran	21	Flame-sprayed aluminum
II (exposed 2-1/2 to 4 years)	27	Chlorosulfonated Polyethylene	31	Aluminum-pigmented epoxy tar	13	Cold-applied coal tar	105	Neoprene
	28	Zinc-filled modified epoxy			29	Epoxy		
	30	Aluminum-pigmented urethane			34	Epoxy		
					100	Coal-tar epoxy		
					107	Aluminum-pigmented chlorinated rubber		
					23*	Saran		
III (exposed less than 2-1/2 years)	Exposure time insufficient for making classification							

*Selected standard

CONCLUSIONS

1. That Kwajalein exposure site has the most corrosive marine atmosphere of the three test sites.

2. That relocation of the test racks at Kaneohe and Port Hueneme closer to the ocean spray would increase the severity of corrosive attack.

3. That exposures at Kwajalein must be from five to six years for unscribed panels, and three years for scribed panels in order to produce significant coating failure.

4. That unsealed zinc or aluminum coatings, at thicknesses of 4 to 6 mils, are unsuitable for protecting steel in a marine atmosphere.

5. That blistering was the major cause of failure of the organic coatings.

6. That, to retard alligatoring, two coats of a coal tar emulsion (MIL-C-15203) are much superior to one coat over a coal tar coating (MIL-C-18480) exposed to a marine atmosphere.

7. That, for 5-1/2 years, under the conditions of this test, the best coating was a mica-filled asphaltic emulsion over a zinc chromate primer, followed in order by a zinc-dust-pigmented inorganic silicate, a furan resin mastic, a vinyl mastic and an aluminum-pigmented vinyl, all of which gave protection superior to that of the selected standard, Saran.

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Appendix A

LABORATORY ANALYSES

System	Coating	Weight/ Gallon (lb./gal)	Specific Gravity (gm/ml)	Viscosity (Krebs units)	Nonvolatile Solids (%)	Pigment (%)	Ash (%)	Nonvolatile Vehicle (%)
1	MIL-C-15328 (Formula 117)1/	—	—	—	—	—	—	—
	MIL-C-15929 (Formula 119)1/	—	—	—	—	—	—	—
	Aluminum-pigmented vinyl topcoat	8.0	0.96	58	27.0	11.0	—	16.0
3	Red lead-epoxy primer2/ (without catalyst)	17.0	2.04	92	77.0	65.0	—	12.0
	Epoxy resin topcoat2/ (without catalyst)	11.8	1.42	100	65.0	46.0	—	19.0
4	Zinc-dust-pigmented inorganic silicate	—	—	—	35.0	—	—	—
5	Vinyl resin primer	11.4	1.36	82	63.0	43.0	—	20.0
	Vinyl resin topcoat	8.7	1.04	64	40.0	12.0	—	28.0
6	Vinyl resin primer	9.4	0.96	67	37.0	20.0	—	17.0
	Viny mastic topcoat	10.0	1.20	86	56.0	31.5	—	24.5
7	Mica-filled phenolic mastic primer (without catalyst)	17.8	2.13	Over 141	96.5	66.5	—	30.0
	Phenolic mastic finish (without catalyst)	13.6	1.64	Over 141	94.0	52.0	—	42.0
8	Vinyl primer	10.7	1.27	89	48.5	32.5	—	16.0
	Furan resin topcoat	8.1	0.97	80	23.5	—	0.16	—
9	Neoprene primer	9.1	1.09	57	40.0	26.0	—	14.0
	Neoprene topcoat (without catalyst)	9.9	1.18	92	60.0	39.5	—	20.5
11	Red lead primer	11.2	1.35	59	60.5	41.5	—	19.0
	Chlorinated rubber-base resin enamel	9.7	1.16	61	46.5	12.0	—	34.5
13	MIL-C-184801/	—	—	—	—	—	—	—
	MIL-C-152031/	—	—	—	—	—	—	—
15	MIL-C-184801/	—	—	—	—	—	—	—
	MIL-C-152031/	—	—	—	—	—	—	—

LABORATORY ANALYSES (Cont'd)

System	Coating	Weight/ Gallon (lb/gal)	Specific Gravity (gm/ml)	Viscosity (Krebs units)	Nonvolatile Solids (%)	Pigment (%)	Ash (%)	Nonvolatile Vehicle (%)
16	MIL-C-15328 (Formula 117)1/	—	—	—	—	—	—	—
	JAN-P-735 (Formula 84)1/	—	—	—	—	—	—	—
	Mica-filled asphalt emulsion	9.3	1.12	58	43.0	19.0	17.0	24.0
17	Gilsonite — asphalt	9.9	1.18	Over 141	76.5	—	34.5	—
20	Zinc metal — MIL-M-38003/	—	—	—	—	—	—	—
21	Aluminum metal — MIL-M-38003/	—	—	—	—	—	—	—
23	Saran resin — orange (Formula 113/49)*1/	—	—	—	—	—	—	—
	Saran resin — white1/	—	—	—	—	—	—	—
27	Vinyl primer	9.0	1.08	102	38.0	27.0	—	11.0
	Chlorosulfonated polyethylene topcoat (without catalyst)	9.7	1.17	Over 141	51.5	30.5	—	21.0
28	Zinc-filled modified epoxy4/ (without catalyst)	9.2	1.10	86	83.5	—	3.8	—
29	Epoxy primer (without catalyst)4/	5/	—	—	—	—	—	—
	Epoxy topcoat (without catalyst)4/	12.2	1.46	122	84.0	43.0	—	41.0
30	Red lead-urethane primer	11.2	1.34	65	52.5	41.5	—	11.0
	Urethane intermediate (without catalyst)	11.7	1.40	61	64.0	42.5	—	21.5
	Urethane aluminum enamel (without aluminum powder)	7.9	0.95	51	—	—	—	—
31	Epoxy tar primer (without catalyst)	15.3	1.83	Over 141	89.0	55.5	45.0	33.5
	Epoxy tar intermediate (without catalyst)	11.4	1.37	Over 141	88.0	—	1.6	—
	Aluminum epoxy-tar topcoat Component A	9.5	1.14	Over 141	64.5	—	0.08	—
	Component B	13.0	1.56	Over 141	85.0	49.0	—	36.0

LABORATORY ANALYSES (Cont'd)

System	Coating	Weight Gallon (lb/gal)	Specific Gravity (gm/ml)	Viscosity (Krebs units)	Nonvolatile Solids (%)	Pigment (%)	Ash (%)	Nonvolatile Vehicle (%)
34	Epoxy primer (without catalyst)2/	9.9	1.19	67	57.0	25.0	—	32.0
	Epoxy topcoat (without catalyst)2/	9.5	1.13	67	53.0	22.5	—	30.5
41	Epoxy primer (without catalyst)	11.3	1.35	86	64.0	37.0	—	27.0
	Primer catalyst — Green2/	7.8	0.94	67	44.0	—	0.20	—
	Epoxy intermediate (without catalyst)	9.7	1.16	61	61.5	15.0	—	46.5
	Intermediate catalyst — Red4/	8.5	1.02	71	72.0	—	5.50	—
	Epoxy topcoat (without catalyst)	9.7	1.16	61	61.5	15.0	—	46.5
	Topcoat catalyst — Yellow4/	8.4	1.00	65	72.5	—	5.50	—
45	Red lead — vinyl primer	10.7	1.27	89	48.5	32.5	—	16.0
	Urethane topcoat (without catalyst)	10.3	1.24	67	59.5	35.0	—	24.5
46	Coal tar urethane (without catalyst)	10.8	1.30	93	77.5	—	22.0	—
47	Wash primer (without catalyst)	7.6	0.91	122	26.0	13.5	—	12.5
	Urethane topcoat (without catalyst)	10.3	1.24	67	59.5	35.0	—	24.5
100	Coal-tar epoxy (without catalyst)	10.7	1.28	Over 141	79.5	—	19.5	—
105	Synthetic rubber primer	7.8	0.93	Under 43	17.0	—	0.12	—
	Neoprene topcoat (without catalyst)	9.1	1.09	88	49.0	25.0	—	24.0
107	Red lead-chlorinated rubber primer	12.8	1.53	100	62.5	39.0	—	23.5
	Aluminum vinyl-chlorinated rubber topcoat — Paste	12.0	1.44	Over 141	67.0	65.0	—	2.0
	Aluminum vinyl-chlorinated rubber topcoat — Vehicle	8.9	1.06	61	41.5	—	—	—

* Present designation is MIL-L-18389 (Formula 113/54).

1/ Meets specification requirements.

2/ Catalyst contains polyamide.

3/ Analytical data not applicable.

4/ Catalyst primarily polyamine.

5/ Not analyzed

Appendix B

THICKNESS OF COATING SYSTEMS

System and Color	Coats (No.)	Thickness (mils)
1. Aluminum-pigmented vinyl resin (gray)		
MIL-C-15328 (Formula 117) Pretreatment	1	0.4
MIL-C-15929 (Formula 119) Primer	2	3.4
Aluminum-pigmented vinyl resin finish	2	2.2
		Total 6.0
3. Epoxy resin (white)		
Catalyzed red lead epoxy primer	2	3.0
Catalyzed epoxy finish	3	5.5
		Total 8.5
4. Zinc-dust-pigmented inorganic silicate (gray)		
Cured zinc-dust-pigmented inorganic silicate	2	3.5
		Total 3.5
5. Vinyl resin (gray)		
Vinyl resin primer	1	1.0
Vinyl resin finish	2	4.5
		Total 5.5
6. Vinyl resin mastic (black)		
Vinyl resin primer	1	1.5
Vinyl mastic finish	2	11.5
		Total 13.0
7. Phenolic resin mastic (gray)		
Catalyzed mica-filled modified phenolic mastic primer	1	10.0
Catalyzed modified phenolic mastic finish	1	5.0
		Total 15.0
8. Furan resin mastic (light gray)		
Iron-oxide vinyl primer	1	0.5
Furan resin finish	6	5.5
		Total 6.0

System and Color	Coats (No.)	Thickness (mils)
9. Neoprene brushing composition (black)		
Neoprene primer	1	1.5
Catalyzed neoprene finish	4	29.5
		Total 31.0
11. Chlorinated rubber-base resin (dark red)		
Red lead primer	1	1.0
Chlorinated rubber enamel	5	4.5
		Total 5.5
13. Cold-applied coal tar base (black)		
MIL-C-18480	4	23.5
MIL-C-15203	2	11.5
		Total 35.0
15. Cold-applied coal tar base (black)		
MIL-C-18480	1	27.5
MIL-C-15203	1	4.5
		Total 32.0
16. Mica-filled asphalt emulsion (black)		
MIL-C-15328 (Formula 117)	1	1.0
JAN-P-735 zinc chromate anti-corrosive primer (Formula 84)	1	1.5
Mica-filled asphalt emulsion finish	7	28.0
		Total 30.5
17. Gilsonite asphalt (black)		
Gilsonite asphalt	5	125
		Total 125
20. Flame-sprayed zinc (gray)		
Flame-sprayed zinc wire		6
		Total 6
21. Flame-sprayed aluminum (gray)		
Flame-sprayed steel wire	1	0.5
Flame-sprayed aluminum wire		4.0
		Total 4.5

System and Color	Coats (No.)	Thickness (mils)
23. Saran (white)		
Saran (Formula 113/49)	6	7.0
		Total 7.0
27. Chlorosulfonated polyethylene (gray)		
Red lead iron-oxide vinyl primer	2	1.5
Catalyzed chlorosulfonated polyethylene finish	5	7.0
		Total 8.5
28. Zinc-filled modified epoxy (gray)		
Catalyzed zinc-filled modified epoxy	3	7.5
		Total 7.5
29. Epoxy (gray)		
Catalyzed epoxy primer	1	2.5
Catalyzed epoxy finish	2	8.5
		Total 11.0
30. Aluminum-pigmented urethane (aluminum)		
Catalyzed red lead urethane primer	3	1.5
Catalyzed urethane intermediate	1	1.0
Catalyzed aluminum-pigmented urethane finish	4	2.5
		Total 5.0
31. Aluminum-pigmented epoxy tar (aluminum)		
Catalyzed epoxy tar primer	1	5.0
Catalyzed epoxy tar intermediate	2	15.0
Aluminum-pigmented epoxy tar finish	1	3.0
		Total 23.0
34. Epoxy (gray)		
Catalyzed epoxy primer	1	1.0
Catalyzed epoxy intermediate	1	1.0
Catalyzed epoxy finish	5	5.0
		Total 7.0

System and Color	Coats (No.)	Thickness (mils)
41. Epoxy (tan)		
Catalyzed epoxy primer	1	1.0
Catalyzed epoxy intermediate	1	2.5
Catalyzed epoxy finish	1	2.5
		Total 6.0
45. Urethane (light green)		
Iron-oxide vinyl primer	1	2.0
Catalyzed urethane finish	2	4.5
		Total 6.5
46. Urethane coal tar (black)		
Catalyzed urethane coal tar	2	8.0
		Total 8.0
47. Urethane (light green)		
Catalyzed wash primer	1	0.5
Catalyzed urethane finish	3	6.0
		Total 6.5
100. Coal-tar epoxy (black)		
Catalyzed coal-tar epoxy	2	14
		Total 14
105. Neoprene (black)		
Synthetic rubber primer	2	0.5
Catalyzed neoprene finish	2	11.0
		Total 11.5
107. Aluminum-pigmented chlorinated rubber (gray)		
Red lead chlorinated rubber primer	1	1.0
Aluminum-pigmented chlorinated rubber finish	3	4.5
		Total 5.5

Appendix C

RATINGS OF COATING SYSTEMS

System	Test Site[1]	Unscribed Panels					Scribed Panels			Comments
		Exposure (years)	Protection Rating	Blistering	Chalking (avg)	Alligatoring or Checking	Exposure (years)	Protection Rating	Blistering at Scribe	
1	Kw	5-1/2	9	2/F	8	10	4-1/2	5	2/D	Slight rusting and blistering present at edges and corners at each site.
	Ka	5	9	10		10	5	8	2/M	
	PH	5-1/2	10	10		10	5-1/2	10	2/F	
3	Kw	5-1/2	9	2/F	6	10	3	5	2/D	Slight rusting and blistering present at edges and corners at each site.
	Ka	5	10	10		10	5	8	2/MD	
	PH	5-1/2	10	10		10	5-1/2	10	10	
4	Kw	5-1/2	8	10	10	10	5-1/2	8	10	Zinc salts and pinhole rust spots present on much of the panel surface at each site.
	Ka	5	9	10		10	5	9	10	
	PH	5-1/2	9	10		10	5-1/2	9	10	
5	Kw	5-1/2	8	2/F	8	10	4-1/2	5	2/D	Slight edge rusting and a few pinhole rust spots present at each site.
	Ka	5	10	10		10	5	9	2/F	
	PH	5-1/2	10	10		10	5-1/2	10	10	
6	Kw	5-1/2	9	2/F	8	10	4-1/2	5	2/D	
	Ka	5	10	10		10	5	9	2/F	
	PH	5-1/2	10	10		10	5-1/2	10	10	
7	Kw	5-1/2	8	2/F	6	10	5-1/2	7	2/MD	Slight edge rusting present at each site.
	Ka	5	9	10		10	5	9	2/F	
	PH	5-1/2	10	10		10	5-1/2	10	10	

RATINGS OF COATING SYSTEMS (Cont'd)

System	Test Site	Unscribed Panels Exposure (years)	Unscribed Panels Protection Rating	Unscribed Panels Blistering	Unscribed Panels Chalking (avg)	Unscribed Panels Alligatoring or Checking	Scribed Panels Exposure (years)	Scribed Panels Protection Rating	Scribed Panels Blistering at Scribe	Comments
	Kw	5-1/2	9	10		10	5-1/2	7	2/MD	
8	Ka	5	9	10	6	10	5	7	2/MD	Slight rusting present at edges at each site.
	PH	5-1/2	10	10		10	5-1/2	10	10	
	Kw	5-1/2	8	2/F		10	5-1/2	6	2/D	
9	Ka	5	9	10	2	6	5	9	2/M	Slight undercutting at edges at Kw. Light checking covered the surface at Ka and PH.
	PH	5-1/2	10	10		4	5-1/2	10	10	
	Kw	3	9	2/F		10	3	5	2/D	
11	Ka	5	9	8/F	6	10	5	7	2/D	Unscribed panel lost at 3 years, Kw.
	PH	5-1/2	10	10		10	5-1/2	10	10	
	Kw	3-1/2	9	10		10	3-1/2	8	2/D	
13	Ka	2-1/2	10	10	6	10	2-1/2	10	10	Slight edge blistering, Kw.
	PH	4	10	10		10	4	10	10	
	Kw	5-1/2	7	2/MD		10	4-1/2	5	2/D	
15	Ka	5	9	10	8	0	5	8	2/MD	Shallow alligatoring present at Ka and PH only.
	PH	5-1/2	10	10		5	5-1/2	10	10	
	Kw	5-1/2	10	10		10	5-1/2	10	10	
16	Ka	5	10	10	8	10	5	10	10	Has given the best protection for over 5 years.
	PH	5-1/2	10	10		10	5-1/2	10	10	

RATINGS OF COATING SYSTEMS (Cont'd)

System	Test Site	Unscribed Panels: Exposure (years)	Unscribed Panels: Protection Rating	Unscribed Panels: Blistering	Unscribed Panels: Chalking (avg)	Unscribed Panels: Alligatoring or Checking	Scribed Panels: Exposure (years)	Scribed Panels: Protection Rating	Scribed Panels: Blistering at Scribe	Comments
17	Kw	5-1/2	7	2/D 2/		10	4-1/2	5	2/MD	
	Ka	5	8	2/F 2/	6	10	5	9	2/F	
	PH	5-1/2	10	10		10	5-1/2	10	10	
20	Kw	2	0	10		10	2	0	10	
	Ka	5	9	10	10	10	5	9	10	Zinc salts present over panel surface at Ka and PH.
	PH	5-1/2	10	10		10	5-1/2	10	10	
21	Kw	2	4	10		10	2	2	10	
	Ka	5	9	10	10	10	5	7	10	Underneath side at Ka rated 2 on protection, and at PH aluminum salts present.
	PH	5-1/2	10	10		10	5-1/2	10	10	
23	Kw	5-1/2	8	2/F		10	3	6	2/D	
	Ka	5	9	10	6	10	5	8	2/MD	Pinhole rust spots present at Kw and Ka.
	PH	5-1/2	10	10		10	5-1/2	10	4/M	
27	Kw	2-1/2	10	10		10	2-1/2	10	4/MD	
	Ka	2-1/2	10	10	6	10	2-1/2	10	10	
	PH	2-1/2	10	10		.10	2-1/2	10	10	
28	Kw	2-1/2	10	8/M		10	2-1/2	10	8/M	
	Ka	2-1/2	10	10	10	10	2-1/2	10	10	Zinc salts present at blisters at Kw.
	PH	2-1/2	10	10		10	2-1/2	10	10	

RATINGS OF COATING SYSTEMS (Cont'd)

System	Test Site	Unscribed Panels					Scribed Panels			Comments
		Exposure (years)	Protection Rating	Blistering	Chalking (avg)	Alligatoring or Checking	Exposure (years)	Protection Rating	Blistering at Scribe	
29	Kw	2-1/2	9	10	8	10	2-1/2	8	2/D	
	Ka	2-1/2	10	10		10	2-1/2	9	4/F	
	PH	2-1/2	10	10		10	2-1/2	10	10	
30	Kw	2-1/2	10	10	10	10	2-1/2	10	2/D	
	Ka	2-1/2	10	10		10	2-1/2	10	8/F	
	PH	2-1/2	10	10		10	2-1/2	10	6/D	
31	Kw	2-1/2	10	10	10	10	2-1/2	9	2/F	
	Ka	2-1/2	10	10		10	2-1/2	10	10	
	PH	2-1/2	10	10		10	2-1/2	10	10	
34	Kw	2-1/2	9	4/F	6	10	2-1/2	9	6/D	Edge blister at Kw.
	Ka	2-1/2	10	10		10	2-1/2	9	4/MD	
	PH	2-1/2	10	10		10	2-1/2	9	8/D	
100	Kw	3	9	4/F	6	10	3	8	2/D	Edge blister at Kw.
	Ka	2-1/2	10	10		10	2-1/2	10	10	
	PH	3-1/2	10	10		10	3-1/2	10	10	
105	Kw	3	8	4/M	2	10	2-1/2	6	2/D	Edge blistering at Kw and Ka.
	Ka	2-1/2	9	4/F		10	2-1/2	9	2/D	
	PH	3-1/2	10	10		10	3-1/2	10	10	

RATINGS OF COATING SYSTEMS (Cont'd)

System	Test Site	Unscribed Panels: Exposure (years)	Unscribed Panels: Protection Rating	Unscribed Panels: Blistering	Unscribed Panels: Chalking (avg)	Unscribed Panels: Alligatoring or Checking	Scribed Panels: Exposure (years)	Scribed Panels: Protection Rating	Scribed Panels: Blistering at Scribe	Comments
107	Kw	3	9	10		10	3	8	2/D	Slight rusting present at edges at Kw and Ka.
	Ka	2-1/2	10	10	10	10	2-1/2	10	2/F	
	PH	3-1/2	10	10		10	3-1/2	10	10	
41	Kw	1-1/2	9	10	4	10	1-1/2	9	6/D	
	Ka 3/	—	—	—	—	—	—	—	—	
	PH	2-1/2	10	10	4	10	2-1/2	10	8/M	
45	Kw	1-1/2	10	10	8	10	1-1/2	7	2/D	
	Ka 3/	—	—	—	—	—	—	—	—	
	PH	2	10	10	8	10	2	10	10	
46	Kw	1-1/2	10	10	6	10	1-1/2	8	4/D	
	Ka 3/	—	—	—	—	—	—	—	—	
	PH	2	10	10	6	10	2	9	8/F	
47	Kw	1-1/2	8	2/M 2/	6	10	1-1/2	5	2/D	Edge blisters at Kw.
	Ka 3/	—	—	—	—	—	—	—	—	
	PH	2	10	10	6	10	2	3	4/	

1/ Kw = Kwajalein; Ka = Kaneohe; PH = Port Hueneme
2/ Blistering at edges
3/ No exposure
4/ Flaking present over 50 percent of panel

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